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MINUTES OF PROCEEDINGS

OF

THE INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XXXVIII.

SESSION 1873-74.—PART II.

EDITED BY

JAMES FORREST, ASSOC. INST. C.E., SECRETARY.

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ERRATA.

Vol. xxxvii., p. 61, line 23, the word "*the*" is omitted before the word "intermediate."

Vol. xxxvii., p. 63, line 3, the word "*sounded*" should be "founded."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1873-74.—Part II.

February 24, 1874.

THOMAS E. HARRISON, President,

in the Chair.

No. 1,308.—"On the Water Supply of the City of Dublin." By Parke Neville, M. Inst. C.E.

The want of a good and abundant supply of water for the city of Dublin had long been felt previous to the adoption of the scheme for obtaining it from the river Vartry, and many plans had been suggested from time to time for its improvement.

Previous to describing the works, now complete, by which the city of Dublin and the suburban districts, from Bray on the south, to the Kilmainham and Clontarf townships on the west and north, have been abundantly provided with pure soft water at high pressure, the history of the supply will be briefly related.

The city was for centuries supplied from the river Dodder, which rises in the Dublin mountains, on the boundary of the County Wicklow, about 12 miles south of the city. This supply has always been vested in the corporation, who at an early period erected a weir across the river at Templeogue, about 5 miles distant, and diverted the water into the city by an open water-course, known as the City water course. In 1308 John Le Decer, first provost of Dublin, "erected, at his own cost, a marble cistern in the public street, for the benefit of the inhabitants, such as was never before seen there:" so that either pipes or a water-course must have existed there previously, for the "High Street" being situate on the top of a hill, there could not have been a natural water-course. In 1394 and in 1397 "William Fitzhenry was sheriff of the County Dublin, and had the custody of the Staines near Dublin, in order to preserve the water-course free

and clear for the benefit of the city." Again, in 1670, it is recorded "that there was a long stone wall built at the south side of St. James's Gate, to convey the water to the new cistern, and that leaden pipes were laid through the city, much larger than the former, for the conveyance of water, which was done at the city's charge."

Prior to the year 1555 the water entered the city in a single stream. At this period a large portion of it, called Coleman's Brook, was conducted along Rainsford Street, Thomas Court, and Thomas Street, while the remainder flowed in a separate course through the Earl of Meath's liberty, called the Poddle. In this year, during the mayoralty of Patrick Sarsfield, a considerable improvement was made by dividing the city water-course by a structure called "the Tongue," about 1 mile outside the present boundary of the city, by which one-third of the water was carried by a high-level conduit into Dublin through Dolphin's Barn, along the rear of the south side of James Street to James Gate, from whence such pipes were laid as were deemed adequate to the supply of the then population of the city; while the other two-thirds continued to flow in the old course, the Poddle.

In the year 1660, the demand for water having overtaken the supply, part of the water-course and the cistern at James Street were rebuilt, so that the supply might more effectually command the higher streets, and a subterranean course was constructed under Thomas Street to a sunken cistern at the south side of New Row, from which a 6-inch main, laid over the old bridge, served the north side of the city. Additional mains and service pipes were also constructed, and in connection with the subterranean course several small cisterns in the streets were furnished with pumps for the use of the poor.

The first Act of Parliament which the corporation obtained with reference to the water supply was in 1720, 6th George III., cap. 16. The following is an extract from it: "Whereas the city of Dublin hath, for many years past, been seized and possessed of a water-course taken from the river Dodder, beginning at the foot of Balruddery Hill . . . . which is the chief supply of water not only for the inhabitants of the said city, but also for his Majesty's Castle of Dublin, and which without it would suffer much prejudice;" and again: "That the lord mayor, sheriffs, commons, and citizens of the city of Dublin, and their successors, shall and may peaceably and quietly possess and enjoy the aforesaid ancient water-course, and have free liberty, from time to time, without being liable to any trespass or other action

for same, to enter, with all necessary workmen, horses, and carriages, on any land or ground through which the said water-course doth run, to dig and trench, repair and amend said water-course and weir."

This Act also gave ample power to prevent trespass, the diversion of the water, or the erection of tuck mills, and to punish parties convicted of polluting the water, by washing dyed woollen clothes, yarn, flax, skins, wool, or garbage of any kind, by a penalty for each offence of 40*s.* and the forfeit of the article, or in default of paying the fine, the offending party to be imprisoned for forty-eight hours, whipped, and kept to hard labour.

In 1721 the corporation found it requisite to construct the James Street basin or reservoir. In order to obtain a better altitude it became necessary to raise the water-course by masonry and embankments through Dolphin's Barn and the commons of Kilmainham. From this reservoir was laid a lead pipe, 10 inches diameter, into James Street, and from this three mains, of 6 inches diameter, were continued into the city, with branches to distribute water to upwards of ninety streets.

In 1735 the necessity of further improvements was discussed. Finally the plans of Mr. James Scanlan were adopted, and he was employed as engineer. He took up the 10-inch main, cut it into short lengths, put eight of them into the James Street basin, and from these he laid mains 6 inches diameter into the city. Further, in conformity with his designs, the corporation purchased for £3,500 the mills and weirs at Island Bridge, and there constructed a "powerful water-engine," by which water was forced through the 6-inch mains to the north side of the city, and from those mains, and others extended through the south side, water was distributed through one hundred and eighty-five streets.

In 1775 the corporation obtained an Act of Parliament to enable them to levy a water-rate or rent on every house in the streets through which they had laid mains. In this year they also entered into arrangements with the undertakers of the Grand canal for "an ample supply of water." Mr. Mylne, of London, was engaged as engineer to the Dublin Waterworks, and under his directions several new mains were laid, the old works repaired, and the city well supplied until 1788, when two 7-inch mains were added, and extensive repairs made. In 1790 Mr. Mylne died. He was succeeded by Mr. James Johnston, by whom additional mains were laid from James Street basin, to supersede the use of the engine at Island Bridge, which had become a ruin.

In the year 1806 contracts were entered into between the corporation and the Grand and Royal Canal Companies for a term of sixty years, securing, so far as could be reasonably calculated on at that period, an ample supply of water for the use of the city. In the year 1809 an Act of Parliament, locally known as the Metal Main Act, was obtained, to enable the corporation to construct extensive new works, and levy additional water rents.

During the ensuing five years the old timber mains (which up to this time had chiefly distributed the water through the city) were taken up or abandoned, metal substituted, and the Portobello and Blessington Street basins or reservoirs were constructed. The former, 2 a. 0 r. 8½ p. in area, and from 8 to 12 feet deep, was supplied, over an overfall gauge weir, 38 feet long, from the Grand canal. The latter, 1 a. 3 r. 3 p. in area, and from 8 to 12 feet deep, was supplied by a similar gauge, 38 feet long, from the Royal canal. The old city basin, James Street, 3 a. 2 r. 13½ p. in area, and from 7 to 12 feet deep, was partly supplied by the old city water-course, supplemented by a supply over a gauge weir, 38 feet long, from the Grand canal. There were eight 7½-inch mains and two 7-inch mains leading out of James Street basin, six 7½-inch mains out of Portobello, and six 7½-inch mains out of Blessington Street basins.

From the date of the completion of the last-named works none of any consequence were executed until 1843, when the corporation laid a 12-inch main from Portobello basin, eastward along the Circular Road, for the better supply of the city, then, as now, rapidly extending in that direction.

In the year 1846 a Dublin Improvement Bill was promoted by the corporation, and a local inquiry under surveying officers was held in January 1847, when the inadequate and bad state of the water supply to the city was proved. In this year another Improvement Bill was promoted by the late Mr. Fred. Jackson, which incorporated a plan designed by Mr. Robert Mallet, M. Inst. C.E., for obtaining a supply of water from the river Dodder. In the following year the same gentleman promoted another Bill, in which was incorporated a plan of the late Mr. Samuel McClean, for obtaining water from the Grand canal near Naas, with an auxiliary supply from the river Liffey. All these Bills failed to obtain parliamentary powers. In 1849 the Government passed the Dublin Improvement Bill, under which the present corporation of Dublin is incorporated, and they came into office on the 1st of January, 1851. While these rival Bills were under discussion, various plans were proposed for the improvement

of the water supply, several of them being for obtaining the supply from high levels on the Grand and Royal canals.

Immediately after the corporation came into office their attention was directed to the water supply, which was defective, the supply intermittent, the pressure weak, the mains mostly much reduced from their original size by a hard calcareous deposit, while portions of the city were above the level attainable by the water.

To remedy this state of things as far as practicable, under the circumstances of the level of the reservoirs, which are only from 76 to 78 feet above Ordnance datum, or 56 to 58 feet above the lowest parts of the city, the numerous 7½-inch pipes leading out of the basins were thrown out of use, and one large main laid from each, and continued considerable distances into the city; several miles of new mains were also laid through streets and districts which, up to this period, were either totally without water or imperfectly supplied. By these improvements a large portion of the city was provided with a constant service of water, but the pressure was very low.

In 1854 the corporation advertised for plans and suggestions as to the best source from which to obtain pure water at a high pressure. They received several communications; and in the latter end of the year obtained the services of Mr. Hawksley, Past President Inst. C.E., to examine the different schemes, and to advise as to the best to be adopted. He recommended that, before making a final report, information should be obtained as to the rainfall, analyses of the waters, &c. Owing, however, to other matters engaging the attention of the corporation, and to monetary difficulties, nothing more was done until 1858, when negotiations were opened with the canal companies, as to the price at which they would undertake to supply a guaranteed quantity of water, from such a level as would secure high pressure. As the canal companies declined to enter into any such contract, the corporation decided on going to Parliament for an independent supply. On the recommendation of Mr. Hawksley and the Author, the plan for obtaining water from the river Liffey, near Newbridge, called the Coyford scheme, was adopted, the necessary surveys were made, and steps taken for an Act in the Session 1859–60.

When the canal companies, and the railway interests identified with them, found that the corporation were really seeking an independent supply, they opposed the Coyford scheme. The canal party stated there was no source of supply like theirs for quality and cheapness, and after much negotiation the Coyford scheme was abandoned, a canal plan adopted, and powers sought from Parliament to carry this out. When, however, the canal interest

succeeded in getting rid of the Liffey project, they again declined to guarantee any quantity of water at high pressure, and the altered scheme being thrown out on standing orders, there was an end to obtaining powers to construct new works that year.

It was now proposed, by the parties in opposition to the corporation, that application should be made to the Government to appoint a Royal Commissioner to examine into all the plans, and that whichever he reported in favour of should be adopted and be supported by all parties. This was agreed to, and Mr., now Sir John, Hawkshaw, Past President Inst. C.E., was appointed Commissioner, under seal dated the 31st of July, 1860, which directed him to inquire into and report on the following points:—

1st. The state of the present supply of water to the city of Dublin.

2nd. The necessity that exists for an improved supply.

3rd. The best source from which such improved supply can be obtained.

Sir John Hawkshaw visited Dublin in August, 1860, and examined all the plans, and the localities from whence it was suggested to obtain supplies of water for the city, which may be classed as follows:—

The Grand and Royal canals.
Lough Owel and Lough Shelin.
The river Dodder.
The Dargle river and Lough Bray.
The river Liffey.
The river Vartry.

Advertisements were inserted in the leading papers, calling on all parties who had sent in plans, or who were in any way interested in the question, to attend before him and state their views; and on the 21st, 22nd, 23rd, and 24th of August the inquiry was held and evidence heard. Mr. Robert Mallet supported his plan for obtaining the supply from the Dodder. Mr. Frith gave evidence in favour of his plan for the Dargle river and Lough Bray. There were several plans for obtaining a supply from the Liffey, viz.:

Poulaphuca scheme.
Morristown ,,
Kippure ,,
Ballysmutten ,,
Coyford ,,

The Poulaphuca scheme was supported by its author, the late Mr. Brazil. The Ballysmutten scheme was supported by

Mr. Bateman, V.P. Inst. C.E. The Vartry scheme was suggested to the corporation by Mr. Richard Hassard, M. Inst. C.E., in 1854, together with another for obtaining the supply from the Grand and Royal canals, which latter he considered the cheapest and most practical. In August 1858 Mr. Hassard met Mr. Hawksley and the Author in the Vartry district, and pointed out the sites of the reservoirs and other works he proposed. A few days afterwards he furnished plans, estimates, and descriptive particulars of his project, which were duly laid before the Royal Commissioner, and from which the scheme as carried out does not materially differ. Mr. Hassard, however, did not attend Sir John Hawkshaw's inquiry; but his plans were submitted by Mr. Hawksley, who stated at the time that the Vartry scheme was an excellent one, indeed the best of all the schemes, if it had not also been the most expensive. The corporation advocated no plan before the Commissioner, but Mr. Hawksley and the Author furnished him, by order of the corporation, with all required information, and had prepared all plans, comparative estimates, and details he directed.

Sir John Hawkshaw sent in his Report, dated the 20th of October, in which each scheme was fully described, and in an Appendix the evidence was recorded. He reported as follows:—

1st. That the state of the present supply of water to the city of Dublin is bad.

2nd. That there is urgent need of an improved supply.

3rd. That the best source from which an improved supply can be obtained is the river Vartry.

Immediately on the receipt of a copy of this Report from the Government, although the result was unexpected, and the estimated cost far more than had been contemplated, the corporation considered themselves bound on the part of the citizens to adopt the Vartry as the source of supply. The Author was accordingly ordered, with the advice of Mr. Hawksley as consulting engineer, to prepare the necessary parliamentary plans, which were duly lodged, and the other measures taken to place the corporation in a position to obtain parliamentary powers to carry out the Royal Commissioner's recommendation, fairly concluding that the parties who had hitherto opposed would consider themselves in honour bound by his decision. But in this the corporation was mistaken; for when the Bill came before the Committee of the House of Commons, in April 1861, it was vigorously opposed by the same parties who had defeated the Coyford scheme. The Ballysmutten scheme was now put forward as a competing plan, but the real

object was to defeat any scheme depriving the canals of the supply. After a severe parliamentary contest, extending over five weeks, the Committee of the House of Commons passed the Bill by a unanimous decision. The Bill was again strongly opposed in the House of Lords, but here the Ballysmutten scheme was not brought forward, as it had transpired that the opposition had no idea of really adopting it, but only used it as a cloak, the object being to retain the supply to the canals. Their Lordships' Committee also unanimously passed the Bill. It was opposed on the third reading in the House of Commons, and at every possible stage, but through the vigilance and energy of Sir John Gray, Chairman of the Waterworks Committee, and the members of the deputation in London, the opposition was defeated, and the Dublin Corporation Waterworks Act of 1861 received the Royal assent on the 22nd of July.

Having now given a brief history of the Dublin Waterworks from a very early date down to the final adoption of the river Vartry as the source from which Dublin and its suburbs were in future to be supplied with water, the Author will proceed to describe in detail the scheme, since executed and now completed.

The river Vartry (Plate 17, Fig. 1) rises in the County Wicklow, at the base of the Great Sugar Loaf Hill, from whence it flows in a direction nearly due south through a thinly populated district, passing by the Devil's Glen, and the village of Ashford, into the Broad Lough, which discharges into the sea at the town of Wicklow. The length of the river from its rise to the sea is 17½ miles, and the total catchment area is 34,890 acres. There are but five mills on its entire length. The only one above the works, at Ballinastow, can work but one pair of stones, occasionally used for grinding oats. Below the works there are three in the Devil's Glen; two sawmills, used for cutting up the timber from the surrounding woods, and a corn mill, having four pairs of stones, belonging to Mr. Tottenham. The lowest on the stream, at Ashford, works but one pair of stones occasionally in grinding oats.

The geological formation of the entire drainage area is the lower Silurian and Cambrian slate, except on the hill-tops to the west, where the granite crops out in spots. It yields a peculiarly soft pure water, during the greater part of the year quite colourless, and the analysis (Appendix, Table I., p. 33) shows it to resemble in quality the Lough Katrine water with which Glasgow is supplied.

Considerable difficulty existed in ascertaining the quantity of

rainfall which could be relied on in the Vartry district, as no rain gauges existed prior to 1860. From the records of these it was calculated that 29·3 inches was the probable average depth of rainfall in dry years; and that allowing 15 inches to be lost by evaporation and absorption, 14·3 inches would remain for the supply of Dublin. The catchment area draining into the river above the proposed works was 14,080 acres, and 14·3 inches of rain over this area would be sufficient to give 12,000,000 gallons per day, or 25 gallons a head for a population of 400,000, and 2,000,000 gallons for manufacturing purposes. In estimating the above quantity as the probable rainfall, care was taken to arrive at the minimum annual fall, making allowance for the possibility of a succession of dry years. This was the more necessary from the fact that, according to the plans lodged in Parliament, it was designed to construct a compensation reservoir on the river at a point (Annagollan Bridge) about 2 miles below the works, to provide against the claims of the millers and riparian proprietors on the river below, so that if the rainfall was taken at too high a figure, it would give them more water than they were entitled to. However, prior to going before the committee on the Bill, this reservoir was abandoned, and it was determined to give money compensation. By this arrangement the corporation have become the sole owners of all the water which falls on the catchment basin above their works, and no party has any right or title to use or divert any of it. The claims of all persons injured, or asserting that they would be injured, by the corporation works and the rights they have acquired being now paid in full, they have, or can have, no further trouble with them, and have obtained the absolute right to and control over all the water that flows into the river above their works. Since 1860 several rain gauges have been maintained in the district, and have been carefully registered, the monthly results being given in tables annexed to this Paper (See Appendix, Table II., pp. 33 to 37). The average rainfall for each year has been as follows:

1861	equal	60·86	inches.
1862	,,	60·65	,,
1863	,,	45·09	,,
1864	,,	47·76	,,
1865	,,	48·69	,,
1866	,,	53·43	,,
1867	,,	46·50	,,
1868	equal	56·15	inches.
1869	,,	49·00	,,
1870	,,	43·68	,,
1871	,,	51·65	,,
1872	,,	69·34	,,
1873	,,	40·08	,,

From these gaugings it is evident that the calculation originally made was erroneous, but fortunately on the right side, as, taking the year on which the gauges registered the least rain, viz., 40·08 inches in 1873, one of the driest years on record, and deducting from this 15 inches for loss by evaporation and absorption, as was done in the spring of 1861, the ascertained rainfall available for the supply of Dublin for this extraordinarily dry year is 25·08 inches against that calculated on in 1861 of 14·3 inches.

Careful observations have been made of the dry weather yield of water from the catchment basin (14,080 acres) for the years 1869 and 1870, and it has been found to be equal to at least 2,500,000 gallons per day during periods of the greatest drought. The water in 1869 flowed over the byewash for one hundred and thirty-three days, and in 1870 for one hundred and seventeen days, and during heavy floods on several occasions as much as 9 inches in depth flowed over the byewash, which is 300 feet in length.

The point selected on the river Vartry as the site of the embankment to form the great storage reservoir is about 7½ miles from its source, and about 1½ mile south-east of the village of Roundwood (Plate 17, Fig. 1). The level of the water in the river at this point was 632 feet above Ordnance datum (low water of a 12-feet tide at the Poolbeg lighthouse, Dublin Bay), and 520 feet above the highest part of the city of Dublin. The level where the river rises is about 1,100 feet above Ordnance datum, and the boundary of the catchment basin on the west varies from 2,384 feet, the top of the Douce mountain, to 1,581 feet, and on the east from 1,200 feet to 800 feet. The entire area is very thinly inhabited. It is chiefly under pasture, and contains but a small proportion of peat land, the shallow bogs that formerly existed in several parts being cut out, and the only turbary of any extent is situated on the side of the Douce mountain. Very little coloured water comes from this, and only after heavy floods in autumn.

The main embankment (Plate 17, Figs. 2), which forms Lough Vartry (the name given to the reservoir), is 66 feet high at its deepest part, and the greatest depth of water is 60 feet. It is 1,640 feet long on the top, and 28 feet wide. The public road from Wicklow to Roundwood, which formerly passed over land now submerged by the formation of the reservoir, has been carried over it. The base at the deepest part is 380 feet wide, the inner slope being 3 to 1, and the outer slope 2½ to 1, and the total quantity of earthwork in it is 320,000 cubic yards.

The byewash, at the eastern end of the embankment, is 300

feet long, and the level is 6 feet below the top of the bank, or 692·45 feet above Ordnance datum. When the reservoir is full at this level the area of land covered is 409 acres, the greatest depth being 60 feet, and the mean average depth 22 feet. Its storage capacity is about 2,400,000,000 gallons, or equal to two hundred days' supply for the city of Dublin and the suburban districts, at the rate of 12,000,000 gallons per day.

Two other embankments had to be constructed (the Knocka-temple and the Watersbridge) to carry public roads across the reservoir; but the entire water is impounded by the one bank above described.

The reservoir and works are surrounded by a boundary wall of rubble stone 5 feet high, the base of which is carried round the reservoir on a contour line 6 feet above top-water line. This wall is about 11 miles long, and incloses, including embankments, filter beds, and the lands purchased by the corporation, 550 acres.

The puddle gutter in the embankment is 6 feet wide at the top (1 foot below the top bank), and 18 feet wide at the level of the old river bed. It has been carried for its entire length down into the solid rock, which was reached at the above point 12 feet below the surface; but on the sides it had to be sunk to from 30 to 40 feet below the surface of the ground. There was not much water met with in sinking the trench; that from the springs was led away in iron pipes through the outer slopes, into drains discharging into the old river bed below the works. On either side of the puddle gutter there was punned clay 10 feet wide, well worked, in layers of 1 foot deep. All the stone and coarse stuff was used on the back of the bank, and only clay and fine stuff in the inner side. The materials forming both sides were carried up in regular concave layers of 3 feet in thickness, and during dry summer weather water was pumped on as the work proceeded to assist in consolidating it.

The pitching on the inner slope varies from 18 inches at the top to 9 inches deep at the bottom, laid on a layer of broken stone 2 feet thick. It has stood remarkably well, although sometimes severely tried by storms from the north-west, which raise high waves on the Lough.

The cill of the waste weir is formed of a double row of granite blocks 6 feet deep by 3 feet thick. The apron is of random rubble pitching, laid on concrete, grouted and pointed with Portland cement. The public road, which passes over the bank, crosses the byewash by a bridge of three arches of 20 feet span, executed in granite ashlar work.

The byewash is carried round east of the filter beds in rock cutting into the old river course, at first in a series of deep steps; but the enormous body of water that rolls down in floods has almost obliterated some of them.

The tunnel under the embankment, used in the first place to pass the river water while the bank was being constructed, and subsequently for receiving the discharge pipes, is situated towards the eastern end. It was formed by cutting an open canal 14 feet wide, with nearly vertical sides, through the solid rock, and covering this with a semicircular arch of ashlar stone, 4 feet thick, well puddled, forming a tunnel 14 feet high by the same width. Through this tunnel a 48-inch pipe and a 33-inch pipe are laid; the former intended for sluicing purposes, should it ever be necessary to lower the water rapidly in the reservoir; the latter for the delivery of water for the supply of the city and suburbs. About midway in this tunnel a stopping of brickwork was built, through which the pipes passed; it was 20 feet thick, constructed of the best Staffordshire blue fire-brick set in Roman cement, and was toothed into rabbeted recesses left for the purpose in the arch, sides, and floor of the tunnel.

The 48-inch pipe commenced at the inner side of the plugging, was continued through the outer portion of the tunnel to a valve chamber, and thence along the eastern side of the filter beds into the byewash. There were two valves; one a throttle valve, with powerful slow-motion gearing, placed in the tunnel about 6 feet from the stopping: the second, a treble-action slide valve, fixed in the valve chamber.

The 33-inch pipe is laid from the bottom of the water tower, which is built at the eastern end of the tunnel on the water side. This tower has three 24-inch valves fixed on pipes laid through the walls, with bell mouths on the outside. The first valve is 10 feet below the top water level, the second 20 feet, and the third 30 feet, to allow the water to be drawn off at different levels. Should it ever be required, water can be drawn off below from the lower level, by opening the 33-inch valve communicating between the 48-inch pipe and this 33-inch pipe in the valve chamber.

The 33-inch pipe is continued through the outer tunnel into the valve chamber, where it is divided into two branches, each of which has a 33-inch valve to regulate the discharge—the pipe for the supply of the city of Dublin, turning off to the west along the outer toe of the bank to the circular receiving basin, from which the water is conducted by canals right and left, and thence on to the filter beds. The other 33-inch branch is laid close to and parallel with the

48-inch pipe on to the byewash, so that it can be used for lowering the water in the reservoir if required.

Before proceeding to describe the remainder of the works, an account of the accident which occurred, by a leakage through the embankment at the tunnel, and of the means adopted to repair it, will be briefly given.

When the embankment had been completed, except a small portion of the pitching, the road-walls, and the metalling of the road, the valves in the valve chamber were shut down on the 21st of July, 1866, and the water commenced rising in the reservoir. On the 4th of October the volume of water impounded was 233,078,204 gallons, showing that in seventy-five days the average yield of the catchments, without the catchwater drain, was equal to 3,107,709 gallons per day.

On the 19th of November, the gearing of the throttle valve not working smoothly, some of it was taken off for alteration; when, either through the carelessness of the party in charge, or from some cause never ascertained, it suddenly closed, and the concussion broke the blade of the valve, and split the pipe in which it was fixed. When this occurred there was a depth of 40 feet of water in the reservoir. There was a considerable leak of water through the split pipe, which was immediately secured in a temporary manner, and the leakage nearly stopped, but it was evident the damaged pipe and the valve would have to be removed; and, on consultation, it was decided to replace the throttle valve by a second screw valve in the chamber.

To enable this to be done entailed either the emptying of the reservoir, which, as a commencement had been made in giving a supply of water to the Pembroke township, was to be avoided if possible, or the stopping of the end of the 48-inch pipe in the tunnel on the inner side. The latter course was decided on; and, as the end of this pipe was 120 feet in from the entrance of the tunnel in the bottom of the reservoir, with 40 feet head of water on it, the work was a difficult one.

A ball (Plate 17, Figs. 3), 54 inches in diameter, made of Memel timber securely bolted together, was weighted with lead, to make it as nearly as possible of the same specific gravity of the water. A strong iron bolt was passed through this, with shackles on each end, and to one end of the bar a strong cable was secured, also a chain (in case of accident to the cable); and by the aid of divers the ball was got into the tunnel to about 30 feet from the entrance. To the shackle at the other side of the ball (intended to stop the 48-inch pipe) was attached a 1-inch rope of sufficient length to reach

the byewash. To this rope was fastened a light, strong fishing-line of equal length, and to the end of this a float just the weight of the water it displaced, so that it would remain in the water without any tendency to sink or rise. The divers took the apparatus into the tunnel as far as they could go, and worked the float about, until at last it was drawn by the current into the 48-inch pipe, and through this into the byewash, a distance of above 700 feet from the mouth of the pipe. A stronger cord was then attached to it, and drawn through, and finally the rope. Several men were then put to pull on the rope, the divers keeping the ball clear of the roof of the tunnel as far as they could, and at last the ball got into the current, which sucked it with considerable force into the mouth of the 48-inch pipe, completely stopping the water from coming through, and forming almost a watertight joint. The man holes were then opened on the pipe in the valve chamber, and a man sent in. One half of the blade of the broken throttle valve was found lying against the slides of the 48-inch valve. The damaged valve and pipe were immediately cut out, a new piece of pipe was put in, and arrangements made for placing the new 48-inch slide valve on the pipe in the valve chamber as soon as it could be got from the manufacturers.

Early in January 1867, there was observed at the east side of the tunnel, about 5 feet above the floor, and 6 feet from the stopping, a small jet of clear water about as thick as would pass through an ordinary quill. The season having been very wet for several weeks, it was thought to arise from some land spring, as it was at the junction of the rock with some masonry used to bring up a vertical wall for the arch to spring from. In a few days it increased, and shifted higher up, coming through a joint in the arch, but still clear water. On the 1st of February the flow became stronger, about as much as would pass through a $\frac{1}{2}$-inch pipe, and slightly turbid. On the 4th it got worse, and the water was deeply coloured, carrying small quantities of clay or sand with it. After a careful survey and inquiries, the Author came to the conclusion that the water from the reservoir was leaking through the bank, and, as the water was then within 5 feet of the top surface, and rapidly rising, that it was necessary prompt measures should be taken. Unfortunately, from the ball being in the mouth of the 48-inch pipe, it could not be made available as intended rapidly to lower the water in case of emergency, and all that could be done was to open the valves in the water tower. The Author then returned to Dublin to report the facts to the chairman of the waterworks committee. After

consultation, Mr. Bateman, V.P. Inst., C.E. and the late Mr. Duncan, M. Inst. C.E., were requested by telegraph to come over at once, and advise what was the best course to be adopted. The next day the water coming through the arch had much increased, and was very muddy. A subsidence was observed in the pitching of the outer slope, about 6 feet in diameter, nearly over the north-eastern angle of the stopping on the reservoir side, and as the pitching continued to sink, clay was filled into the hole.

The Author had visited the scene of the disaster at the Agden reservoir, Sheffield, immediately after the accident occurred, and naturally felt much alarm. He knew there was nothing in common as regarded either the nature of the ground on which the embankments were placed, or of the mode of construction or material used, and that there was no possibility of the Roundwood embankment going as the Agden did. Yet as the reservoir was within 4 feet of being full, and as rain, snow, and storm were constantly recurring, his anxiety was very great. To add to the misfortunes, at this time the new 48-inch valve was being inserted, and till this was done, and the pipe made good, no attempt could be made to get out the ball.

Mr. Duncan arrived at the works on the night of the 6th, and gave most valuable assistance; remaining with the men working in the valve chamber night and day, encouraging them as the water through the arch of the tunnel gradually increased in volume, and extended nearer the valve chamber, which made them rather timorous, especially as they were exhausted from want of sleep. By the 10th the valves and pipes were all in working order, and then every effort was directed to extract the ball.

On Mr. Duncan's arrival it had been decided to cut a gap in the byewash weir. By working men in relays, day and night, a gap had been rapidly made, 20 feet wide by 6 feet deep, which quickly lowered the water in the reservoir from 3 feet to 4 feet, and prevented its rising. On the arrival of Mr. Bateman he made a careful examination of the bank, in conjunction with Mr. Duncan, and after the fullest investigation they gave it as their opinion that no immediate danger was to be apprehended, but that every exertion should be made to lower the water in the reservoir, to discover the cause of the leak, and to repair it.

Immediately on the valves being restored, divers were sent down to ascertain that the cables and chain attached to the ball had not been injured by chafing against the masonry, stones, &c. Heavy anchors were also sunk in the reservoir, through the

shackles of which the cable was passed, and then brought up the slope of the embankment to a powerful winch, placed on the roadway. The communication pipe between the 33-inch and 48-inch pipes was next opened, to equalise the pressure on the ball (the outlet valves being closed), and efforts were made to pull out the ball, but, owing to the pressure of the water on the reservoir side being greater from the leakage round the ball than on the down side, it could not be moved. A 4-inch pipe was therefore attached to the 48-inch, and carried up the outer slope of the bank into a cistern elevated 15 feet above top water, into which water was pumped by a steam fire-engine, so as to create a greater head of water on the land side of the ball, and all the time the utmost strain attainable was kept up on the ball. Two or three times it was started, but sucked back again; at last, by untiring efforts, about 1 A.M. on the the 15th, it was drawn free of the 48-inch pipe. It remained fast in the tunnel, but the cable and chain attached to it were fastened up as tight as possible. Then the 48-inch valve was opened gradually, so as to allow a flow equal to an ordinary winter flood to pass down the river, as, had this valve been opened fully, the quantity of water discharged under a 50-feet head would have done much damage. The valve was opened wider as the water lowered, and by the 2nd of March the reservoir was emptied, without the least injury to property down stream.

The Author thinks it only due to the memory of the late Mr. Duncan to record the fact, that to his indefatigable personal attention and practical knowledge, working night and day in the most inclement weather, is mainly owing the successful overcoming so quickly of the great difficulties of the situation.

The next question, and one of no small difficulty, was to ascertain where the leak had taken place, and to cure it. It was first suggested to sink a shaft of sufficient size through the embankment down to the stopping, but after careful consideration it was decided to cut down on the stopping. The contractor and the corporation having agreed to leave the question of liability as to the cost of finding out the leak, and then of repairing the embankment, to Mr. Bateman, the work was carried out according to his plans by the contractor, under the joint supervision of Mr. Bateman, Mr. Duncan, and the Author.

A cutting on the longitudinal section of the bank of about 300 feet long at the top, and 70 feet long at the level of the floor of the tunnel, was made, to expose that portion of the tunnel in which

the stopping was situated, as well as a portion of the tunnel for about 20 feet on either side of it. The slopes of this cutting were about $1\frac{1}{2}$ to 1, and the puddle gutter was carefully sodded over during the progress of the excavation.

When the excavation reached the puddling over the arch of the tunnel at the north-east corner, the puddle was found nearly destroyed, the clay being washed out, and but little material left, except gravel, sand, and stones. This point was just under where the subsidence took place in the pitching on the outer slope of the embankment before mentioned. As the excavation proceeded, it was found that the leak was caused by the water creeping from the reservoir between the rock and the puddle, and softening the latter where the space between the brickwork and the rock was narrow, and at a spot where the water from a spring, discovered in excavating the ground for the puddle gutter, had been led outwards into the reservoir end of the tunnel, while the excavation for the puddle gutter was made, and the puddle got into it. From this point the water made its way towards the land side of the stopping by two courses, partly by creeping between the rock and the puddle on the east side, but chiefly between the puddle and the brickwork of the tunnel in which the stopping was built, and so on until it pierced the puddling, and penetrated the side and arch of the outer or open end of the tunnel. The quantity of clay washed out of the puddle was considerable, but the sand and gravel remained. There were no large holes, nor had the puddle been dragged from or settled from the earthwork. The material put in to fill up the hole, formed by the sinking of the pitching on the reservoir side of the bank, had evidently been carried down, and the peat, mould, ashes, straw, &c. were found in the softened puddle through which the water leaked.

The experience gained in investigating the cause of this accident would certainly suggest a material alteration in the way the cutting had been made through the rock for the tunnel, round the stopping, and in the use of puddle between the brickwork and the rock; yet, had it not been for the action of the water from the spring, it is doubtful if this leakage would have occurred.

The leakage and all the circumstances connected with it having been developed, the plan for repair and reconstruction was determined on by Mr. Bateman, in consultation with Mr. Duncan and the Author.

The rock was excavated on each side of the tunnel where the stopping was situated several feet wider than before, the

rock being cut to a slope towards the tunnel of about 1 to 1, and then stop walls of fire-brick and cement were built across each end of the old stopping. These walls were 4 feet thick, and were carried down 4 feet below the bottom of the tunnel in the rock. They were continued also through the side walls and the arch so as to tie the rock on each side where practicable, and they were carried above the upper side of the arch about 3 feet. The space between these stop walls, over the arch of the tunnel, and along the sides of it, was then filled in with cement-concrete, so as to form a solid mass, the upper sides of the concrete being sloped or bevelled off so as to form inclined beds for the puddle to lie on, avoiding all vertical jointing. The concrete was formed of 2 parts of broken stones, 2 parts of gravel, 1 part of sand, and 1 part of the best Portland cement. In the bottom, where the excavations were below the floor of the tunnel, fine grout of gravel, sand, and cement was used, the proportion of the cement to the other materials being largely increased. Concrete was also used to fill up all hollows or holes in the rock cutting, until perfectly clean, smooth, inclined beds were formed for the puddle to rest on.

A pier of masonry in cement was at the same time carried up, to support the land end of the bridge giving access from the top of the embankment to the water tower.

The entire space over the concrete, to a height of 12 feet above the top of the arch, was then filled in with carefully-worked puddle; and from this level the puddle gutter was carried up, along with the making good of the embankment where it had been cut down, in the usual manner, the new puddle being carefully tied into the old puddle by a rabbeted junction. The filling for the bank was carried up in thin layers, well rammed, and, in dry weather, watered, so as to get it consolidated. This was most satisfactorily done, which has been proved by the fact of there being hardly any subsidence, and no crack or dragging in any part of the work, up to the present date.

The water from the spring before referred to gave some trouble during the execution of the works of repair; but it was kept back with brick and cement from the puddle until the work was carried to such a height as to permit of its being carried off in a pipe. The springs on the land side were also conveyed away, as originally intended, by iron pipes into the drains.

To afford easy access to the 48-inch pipe from the reservoir side in case of accident, the pipe was continued through the inner tunnel into the reservoir and carried through rock excavation

under the northern wall of the water tower, where it terminates with a bell mouth, into which a ball valve can be lowered, by a chain passing over a cantilever beam, with a pulley at the end which has been fixed in the tower. The ball valve is placed in a barge built purposely for it with movable sides, and is kept in a boat-house at the western end of the embankment. When wanted it can be easily towed under the cantilever derrick at the tower, and lowered by a chain, worked by a windlass on the embankment into the bell mouth. One of the 48-inch valves wanting repair, the ball valve was brought out of the boat-house and lowered into the bell mouth in about half an hour from the time the barge left the boat-house, and it fitted so tight that there was but little leakage. The blades of the valve were taken out, repaired, and put back, and the ball was raised without difficulty, and replaced in the boat-house in an hour from the time of commencing the operation of raising it, including the time occupied in fixing the windlass and adjusting the chain.

The repair of the embankment having been completed, all but the building of the road walls, the water was impounded from the 10th of January, 1868, with the following results:—

				Feet below High Water.	Quantity of Water Impounded.
On the	1st	of March	the Water was	26·1	405,274,394
,,	,,	April	,,	11·4	1,303,238,412
,,	,,	May	,,	8·0	1,590,176,513
,,	,,	June	,,	6·9	1,688,993,956
,,	,,	July	,,	9·3	1,477,204,600
,,	,,	August	,,	14·0	1,102,021,019
,,	,,	September	,,	14·9	1,036,019,355
,,	14th	,,	,,	17·2	871,206,257
,,	1st	October	,,	4·1	1,953,722,144
,,	14th	,,	Reservoir flowed over		2,374,358,344

By the above it will be seen that from the 10th of January to the 1st of June the volume of water impounded was 1,688,993,956 gallons, equal to one hundred and forty days' supply for the city at the rate of 12,000,000 gallons per diem. During this period there were drawn off daily an average of 8,000,000 gallons for the supply of parts of the city and for the Pembroke and Blackrock townships. For the following four months the water diminished in the reservoir; but at the end of this period seventy-three days' supply, at the rate of 12,000,000 gallons per diem, were in store. In the interval there had been a very dry season, the water was gradually supplied to the greatest part of the city, and, owing

to the bad fittings and the difficulty of getting the public to renew them with others of proper strength and quality to bear the high pressure, the waste was so great, that for some time the consumption was from 17,000,000 to 18,000,000 gallons per day. Between the 14th of September and the 14th of October there was impounded the enormous quantity of 1,503,152,087 gallons, or ninety-seven days' supply at the rate of 12,000,000 gallons per diem in excess of the quantity drawn for the maintenance of the city and suburban supply. The quantity of water now required for the supply of the city of Dublin, the Pembroke, Blackrock, Kingstown, Bray, Dalkey, Killiney, Ballybrack, Clontarf, and Kilmainham townships is between 14,000,000 and 15,000,000 gallons per diem. This may be considerably reduced by checking waste; but assuming this rate, and with the dry-weather yield from the catchment of the Vartry, at 2,500,000 gallons per diem, the greatest quantity that will be required to be drawn is from 11,000,000 to 12,000,000 gallons daily, so that the storage capacity of the reservoir is equal to seven months' supply, supposing no rain to fall during that period.

The 33-inch pipe is carried from the valve chamber, and discharges into the centre of a circular receiving basin 87 feet in diameter and 6 feet deep, of granite ashlar (Plate 18, Fig. 1), from which two conduits lead the water on to the filter beds. This pipe is also continued under the pure water tank No. 1 to the outlet wells (Figs. 3) from the pure water tanks Nos. 1 and 2, so that, by working the valves, the water can either be conveyed from the central receiving basin on to the filters, or, if necessary, be passed direct into the pure water tanks without filtering.

The filter beds (Plate 18, Figs. 2) are seven in number, four on the west and three on the east side of the pure water tanks. Each filter is 215 feet long by 115 feet wide at the top, and 187 feet by 89 feet at the bottom. They are 10 feet deep from the floor to the level of the roads, and contain a layer, 6 feet 6 inches thick, of filtering material, viz., on the bottom, 2 feet 6 inches of stones broken to pieces of about 4 inches diameter, on this three layers of different-sized gravel, and on the top 2 feet 6 inches of washed sand. It was intended to work the filters with about 2 feet head of water, but as under that head the percolation was not sufficiently speedy to supply the demand, there has often been a depth of 3 feet of water on them. As this rapid filtration does not clear the water so well as the slower operation, the corporation have obtained power to con-

struct additional filter beds, which will meet all the requirements at the rate of filtration originally calculated, and this work is now in progress.

The sites of the filters are chiefly excavations into the rock, but in parts they are made up by embankments, and in the latter case the slopes are pitched with rubble stone. The slopes are 2 to 1 to the top of the filtering medium, and 1 to 1 below this. The roads all round and dividing the filtering beds are 20 feet wide, 16 feet gravelled, with sodded margins 2 feet wide on each side.

The water is passed from the canals on to the filtering beds through culverts 3 feet square, having iron sluices worked with screws to regulate the flow, and it is distributed by wooden shoots so as not to disturb the sand. It descends through the filtering material, and is collected in two drains of dry rubble masonry, which conduct it into vertical shafts (one for each filter), in which it rises and then flows out through culverts into the pure water tanks.

The pure water tanks are 250 feet long, and 150 feet wide at the top, and 200 feet by 102 feet at the bottom, and are 12 feet 6 inches deep from the surface of the ground, with a depth of water of 11 feet. They were partly excavated out of the rock and partly embanked; in the latter case (as also for the filter beds) puddle gutters excavated far down into the solid rock have been in all cases carried round them.

The total area of land occupied by the filter beds, tanks, and grounds below the embankment is about 50 acres.

All the water from the springs met with in the puddle trench and in the outer tunnel and under the back of the bank has been carried to the outer side of the embankment by iron pipes into drains; these lead into a well near the receiving basin, whence the water is conducted by a 12-inch iron pipe into the cleansing pipe from the pure water tanks, and by this discharged into the old river bed just outside the works. This well affords a means of daily observation of the increase or diminution of the flow of water from them, and has proved most useful by leading to the immediate discovery of a leak from the receiving basin, and another from the canal opposite the valve chamber, caused by some dragging or defect in the puddling.

A sand washing machine has been erected at the filters. It is nearly the same in design as that in use at the Liverpool waterworks at Rivington, and was manufactured by the same maker, Mr. Sampson Moore, of Liverpool. It is worked by a small turbine wheel, the head of water being derived from the reservoir. It

acts remarkably well, and washes about 50 cubic yards of sand per diem, without the dirt, smoke, and expense for coal, engine, man, &c., attendant on the use of steam power as at the Liverpool works.

The water is conveyed from the pure water tanks to the tunnel through an iron pipe. This is for the first 150 yards 33 inches in diameter, and for the remaining 670 yards 42 inches, the fall from the top water level in the tanks being equal to 45·5 feet per mile.

The tunnel to convey the water from the valley of the Vartry under the range of hills dividing it from the districts to the east, which slope towards the sea, is 4,332 yards long. At the commencement it takes a south-easterly direction, but is curved round in its course, so that at the discharging point, at Callow Hill, the direction is north-east, thus diverting the water from flowing southwards towards Wicklow to nearly north towards Dublin. The tunnel was driven from twenty-one shafts, each 200 yards apart. The first shaft was commenced on the 4th of January, 1863, and the last heading was opened out in September, 1866; thus the total time taken to drive the tunnel was three years and eight months. The contractor thought he could execute the works by sinking only eight shafts, and these he made rather small. But in August 1863, from the slow progress of the work, he was compelled to sink the number originally designed. The quantity of water met with rendered it necessary to substitute steam power at several of the shafts for the horse gins first used for working the pumps.

The difficulties met with in driving the tunnel were, 1st, the hardness of the rock; 2ndly, the irregularities of the stratification and the thinness of the layers, which were frequently horizontal; and, 3rdly, the quantity of water.

The rock was of the lower Cambrian or Silurian system. The layers varied from 1 inch to 24 inches in thickness, the thinner prevailing, and of different hardness. Frequently several beds would be crossed in all directions like lattice-work with quartz veins, and then would come green stone or highly indurated slate, next, a layer of almost pure and highly crystallised quartz, and afterwards, perhaps, a layer of soft clay slate. The green stone and quartz blunted the jumpers after a few strokes, and the miners had often to wrap tow round the jumpers to protect their hands from the sparks. From thirty to forty drills of the best steel, costing £38 per ton, were frequently blunted in making an 18-inch hole. In one heading it took one ton of steel to pierce 280 yards of tunnel. These particulars applied to the tunnel

between shafts Nos. 1 to 11. The rock from shafts 11 to 20 was of a more slaty character, contained fewer quartz veins, and was more easily worked. The layers often had to be blasted separately without regard to their thickness, as the powder took little effect if the bore hole was driven forward through several layers, and as little material could be got out with the sledge or stone pick, the cost of blasting and boring was very great.

Seams charged with water were in several instances encountered crossing the beds at nearly right angles; some of them appeared to be fed from caverns or subterranean reservoirs, and several remarkable cases were met with. A shot fired in a heading from shaft No. 5 opened a large fissure, from which water rushed out with great force, immediately flooding the heading, and a strong stream continued to flow from it. In another case, in heading No. 1, shaft 10, where the jumper was suddenly driven into soft rock, the pressure of the water violently forced it out again, and the water continued to flow as from a pipe under the pressure of several feet of water. Between shafts Nos. 4 and 7 it was seldom a hole could be bored without tapping more or less water, entailing a great deal of trouble, delay, and waste of powder.

Nitro-glycerine and gun-cotton were tried at times, but the miners had a great objection to them, especially to the former, from fear of accident in handling it. Further, it was found, from the thinness of the layers of rock, and the small face to work on, that their greater blasting power could not be well or economically employed.

By the contract the tunnel was to be 5 feet high by 4 feet wide, egg shaped, with the large end downwards, with a regular fall of 4 feet per mile, and it was commenced of these dimensions. Soon, however, the contractor found it advantageous to enlarge the size, as the work was thereby carried on more quickly. For the greater part the tunnel has been excavated about 6 feet high by from 4 feet to 5 feet wide. The bottom has been dressed off smooth, but the upper part of the sides and the roof have been left rough, and wherever there was soft rock of a treacherous character, that part has been lined with brick set in Portland cement.

The driving of the tunnel was chiefly let to miners in small contracts; the miners provided the powder, fuze, sharpening drills, candles, and two banksmen and a boy; while the contractor found steel hammers, picks, barrows, engines, engine men, and plant, and kept all the pumps and air fans in order.

The average rate of sinking the shafts, which varied from 180 feet to 90 feet in depth, was 3·7 feet per week, and for the tunnelling 3·68 feet per week at each face. The average cost of sinking the shafts was £19. 1*s.* 9*d.* per lineal yard, and for driving the tunnel £9 19*s.* 6*d.* per lineal yard. The total cost of the tunnel, without lining or towers, was £57,766. The dip of the rock was in most parts 25° to 35°, and the rock was more easily separated by blasting in sinking the shafts than in tunnelling; but on account of the greater difficulty in keeping the bore holes in the shafts clear of water the average progress in both was nearly equal.

Tables III. and IV. in the Appendix (pp. 38 to 41) show the time occupied in sinking each shaft, and in driving the different headings.

Had the contractor commenced sinking the twenty-one shafts in January 1863, and at once provided steam power for working the pumps, the tunnel would probably have been completed in about two years and three months.

A boring machine, invented by Mr. Robert Low, was for a time employed at the Callow Hill end of the tunnel, but did not act effectively. It was designed to work two jumpers at once, but from the size of the tunnel only one could be used. Various forms of points were tried on the jumpers, such as the cross, the Z-shaped, and the common chisel point, and the latter was ultimately adopted as the best. In the first trials it bored a hole 1 inch in diameter at the rate of about 1 inch per minute, a result so tempting, considering the backward state of the work at the time, that it induced Messrs. Edington and Son, of Glasgow, who then carried on the works, to get two made with some improvements, and these were placed in the headings between shafts Nos. 5 and 6. The one in the heading from shaft 5 was soon discontinued, but that in heading No. 1, shaft 6, was worked for upwards of six months, with a rate of progress in the tunnel of 5 feet 3 inches per week. In the opposite heading from the same shaft the men worked three shifts of eight hours each, and as greater energy was exerted there than at any other part of the tunnel, the average progress was at the rate of 5 feet 6 inches per week. There was in this a saving in engine power, candles, &c., and the result was that hand labour was more successful than the best of the machines tried. Besides, in the heading driven by the machine from 30 to 40 pounds of powder were used per yard forward, and the corners and heels of rock had to be dressed by hand to bring the tunnel to form, while the heading driven by

hand labour took at most about 25 pounds of powder per yard forward.

A boring machine, invented by Major Beaumont, R.E., M.P., was also tried, and the experiment was continued for about eight months, at great cost to the inventor. But the machine was evidently more suited for shaft sinking and tunnelling in soft rock of uniform texture than to act on the porphyritic green stone and the quartz rock in shaft No. 2. It bored a smooth circular tunnel 6 feet in diameter. In the Paris Exhibition of 1867 this machine cut through blocks of freestone with great effect.

The power used in working both machines was compressed air, and the atmosphere in the tunnel was thereby kept in a cool and healthful condition for the miners.

At the northern end of the tunnel, at Callow Hill, a cast-iron gauge weir, with a sharp edge of the most approved section, has been erected for registering the quantity of water passed down daily for the supply of the city and suburban districts. The water is measured six times daily by a floating meter. The weir is divided into two bays 10 feet each in length, over which the water falls into a circular basin 86 feet in diameter and 10 feet deep. The level of the water in this tank, when full, is 602 feet above Ordnance datum, and from it a main 33 inches in diameter conveys the water to the service reservoirs at Stillorgan. Several carefully made experiments have proved that the quantity of water, calculated by the usual formula for ascertaining the flow of water over weirs, was larger than the amount actually discharged by about 8 per cent.

The length of the 33-inch main is 17 miles 4 furlongs 142 yards, or 30,942 yards, and the falling line is 20 feet per mile.

Three relieving tanks are constructed on the line of main at different points, viz.:

	Feet above Ordnance datum.			Yards.
At Kilmurray	473	distant from	Callow Hill	11,809
„ Kilcroney	414	„	Kilmurray	5,121
„ Rathmichael . . .	341	„	Kilcroney	6,444

The tank at Rathmichael is 7,431 yards from the Stillorgan reservoir. At each tank, as also at Callow Hill, there are self-acting drop valves to shut off the water in case of the pipes bursting. The main is laid for 9,894 yards along the public roads, and the rest, 21,048 yards, across the country. Where it passes through the

Glen of the Downs there is a high pressure, in some places above 300 feet of water; and it had to be carried over rough ground in crossing the valleys of the Dargle, Cookstown, and county boundary rivers, and thence to the Rathmichael tank.

The pipes, valves, and iron-work were manufactured by Messrs. Edington and Son, of Glasgow, who also took the contract for the pipe laying. On this long line of pipe there have been only sixteen cases of burst pipes, twelve of them while the contractor was in charge of the work, and four since. Only in two cases, one at Newtown Mount Kennedy, and another at Kilpedder, was serious damage done: there were in addition a few cases of drawn joints. Table V. in the Appendix (p. 42) shows the thickness of the pipes, and the pressures they were calculated to bear.

The distributing reservoirs at Stillorgan (called the Prince of Wales's reservoirs) are 4 miles 5 furlongs 150 yards from the city boundary at Eustace Bridge. The top water level in the upper reservoir is 274 feet, and in the lower 271 feet above Ordnance datum, or about 250 feet above the level of the quays and streets in the lowest parts of the city, 230 feet above the average level, and 170 feet above the highest part of it. The lower reservoir contains 43,166,548 gallons, with an average depth of about 22 feet of water; the upper reservoir contains 43,057,424 gallons, with an average depth of about 20 feet of water. The total area of land under reservoirs, embankments, water-courses, and ground, within the boundary walls, is 26 acres 30 perches. The reservoirs are formed partly by excavation and partly by embankment, the deepest excavation having been about 15 feet, and the highest embankment 26 feet; the excavations were chiefly in hard yellow and blue clay, and in soft rotten granite rock. The puddle gutters were carried down into the solid granite rock, in every case but one, where there was a fault. In this instance, at a depth of 30 feet, there being no change, the excavation was filled up with cement concrete to the level of the bottom of the trench under the puddle on each side. The banks are 12 feet wide on the top, which is 4 feet above top water level, and the slopes are 2 to 1, the inner slope being pitched with granite rubble. The pipes are laid in such a manner that the water can be admitted into either of the reservoirs at pleasure, or it can be passed direct, without entering them, into the screen chamber (Plate 18, Figs. 4). This is a handsome octagonal building, of granite ashlar, situated at the south-eastern angle of the lower reservoir. It is 46 feet wide

at the bottom, and 49 feet at the level of the floor, each side being about 20 feet long on the floor line. The screens are distant 10½ feet from the walls towards the centre of the chamber; they also are arranged octagonally on plan, to correspond with the building, each side being about 10 feet long. The depth from the bottom of the chamber to top water is 27 feet, and to the floor line 31 feet 8 inches. The pillars and framework of the screens are of cast iron. The screens are of copper wire gauze, having thirty strands to the square inch, and the entire area of the screens, through which the water is passed, is 1,500 superficial feet. Seven 33-inch valves are placed on the mains in this chamber to allow the water to be drawn from either of the reservoirs as necessary, and also from either side of the screens. Two 27-inch mains, controlled by two 27-inch valves, convey the water from this chamber to Dublin, and a 15-inch main is laid out of it for the supply of Kingstown and Dalkey. There is also a scour pipe, 12 inches in diameter, from the chamber into a sewer to enable it to be cleansed or the screens repaired, and the overflow is through a vertical 27-inch pipe with a bell mouth. The valves are worked by gearing fixed against the walls, so that the centre of the chamber is clear. All the valves here, as also at Roundwood and along the line (except the self-acting valves) are fitted with slow-motion gearing, so that it requires about thirty minutes to entirely open or close any of the valves. On each valve brass indices, graduated both by inches and turns of the screw, register the exact number of turns of the screw, or the number of inches the valve has been moved up or down. The floor of the chamber is of cast-iron plates of a handsome pattern, and so arranged that any one plate can be taken up at pleasure. The height of the walls of the chamber to the wall plate is 15 feet, and the chamber is covered by an ornamental iron roof slated over.

The works connected with these reservoirs were successfully carried out without accident or defect of any kind; and the contractor both here and at Roundwood executed the masonry in the most unexceptional manner.

The two 27-inch mains which convey the water to Dublin from the screen chambers are carried under the embankment in a culvert, at the outer end of which there is a vaulted chamber, where self-acting valves are placed on the mains, and from thence their course is along the high road to the city at Eustace Bridge. At Merrion Avenue, Simmons Court, and at Leeson Street, groups of valves enable the lines to be connected, so that in case of accident

one section of either main can be emptied while a burst pipe or blown joint is being repaired, without interfering with the supply of water to the city. At these points, also, branch mains for the supply of water to the Blackrock and the Pembroke townships are taken off, the valves in all cases being placed in vaulted chambers of easy access.

The 33-inch main was calculated as being capable of conveying from 15,000,000 to 16,000,000 gallons of water per diem to the city, &c., but in practice it has been found capable of conveying above 20,000,000 gallons.

At the north side of Eustace Bridge, in Leeson Street, the lines of 27-inch main separate. One is carried in a north-westerly direction by Stephen's Green South, Kevin Street, and the Coombe; then turning north through Meath Street to Thomas Street, where its diameter is reduced to 24 inches; it continues by Bridgefoot Street, and crosses the river Liffey at the Queen's Bridge to Queen Street, where the diameter is reduced to 18 inches, and at North King Street it joins an old 12-inch main. The other main is carried in a north-easterly direction by Fitzwilliam Street, Merrion Square, Holles Street, and Sandwith Street, to Great Brunswick Street, where it turns west to Carlisle Bridge, across which it is carried into Sackville Street; here its diameter is reduced to 24 inches, and continued north by Cavendish Row, where there is a further reduction in size to 18 inches, then by Frederick Street to Dorset Street, where it joins the old 12-inch main, which continues westward through Bolton Street and North King Street to join the other line of main at the top of Queen Street as before described; thus forming a great encircling artery, from which all the minor distributing mains and pipes are fed. At the intersection of every street a screw valve enables the water to be cut off with great facility and rapidity in cases of burst pipes or for repair, or in the event of fire increased pressure can be rapidly brought to bear in the particular district requiring it. Since the Vartry water has been introduced into the city, the necessity for maintaining fire engines has ceased. In every case of fire which has occurred (and there have been several serious ones), the water thrown from the mains, by simply attaching a stand pipe and hose to the hydrants, has been found sufficient to extinguish the largest fire, with a rapidity which no number of steam or hand fire engines could effect.

The hydrants are of the pattern known as Bateman and Moore's patent. They are about 100 yards apart, and the total number put down has been 1,219.

The total length of new mains laid in the city, and of old ones taken up, cleansed, and relaid, has been as follows:—

5,179	lineal yards	of	27-inch	main;
466	„	„	24	„
3,169	„	„	18	„
1,442	„	„	12	„
495	„	„	10	„
5,223	„	„	9	„
3,911	„	„	7½	„
6,361	„	„	6	„
1,900	„	„	5	„
35,174	„	„	4	„
24,882	„	„	3	„

or about 50 miles, which, added to a length of 60 miles of old mains utilised, makes the total length of the pipes within the city 110 miles. About 21 miles of the old pipes have been taken up; of these, about 9¾ miles, after cleansing and being proved, were relaid, and are included in the above return. They were chiefly 3-inch and 4-inch pipes.

Wells for the use of the poor have also been erected in several parts of the city, and in small courts and streets.

The number of screw valves put down of different sizes has been 1,148, and all the old clack valves and Gavin plug hydrants have been taken up.

Every part of the city is now effectively supplied with water, and the service affords universal satisfaction.

The old mains, and the lead service pipes, were all to a greater or less degree coated on the inside with a calcareous deposit of lime and iron derived from the canal water. In the larger pipes this used to accumulate to the thickness of an inch, and reduce their bore by a third or a fourth, thus interfering with their powers of supply. In such cases the deposit was removed by powerful scraping machines. When the soft Vartry water was let into the pipes so coated, it acted as a solvent, and detached the coating from the pipes; so that a dirty, muddy deposit was found, which was worked up in the water by the current and by the action of opening and shutting the valves. This was for some time a cause of great complaint, the public attributing the evil to the "bog water" the corporation had brought into the city; but the annoyance has long passed away.

Prior to introducing the Vartry water into the city, notice was given to the public informing them that the water was about to be laid on at high pressure, and calling on them to have their service pipes, taps, cisterns, and other fittings examined and made suitable,

and sample fittings were exhibited in the corporation offices. But few persons took notice of the caution; and when the water was let on street by street, the commotion it caused was great, and the rate of pay for plumbers rose to a large premium. For months the waste from this cause was enormous, requiring for some time 18,000,000 to 19,000,000 gallons per diem to keep up the supply, or double what it ought to be. The waste was gradually diminished by the introduction of new fittings, and by the efforts of the waste-water inspectors. The consumption now is, for the city and out townships, about 14,000,000 gallons of water per diem: this is still from 3,000,000 to 4,000,000 gallons per day too much, and chiefly arises from the carelessness of the public in allowing water taps to remain open (often on purpose, with the idea that it flushes the drains), the use of dill closets, and the overflow pipes from the cisterns.

By the old system the charge for water in Dublin for manufacturing purposes was made according to the diameter of the pipe, without regard to the size of the main tapped or the pressure. The party obtaining the supply in this way was allowed to use or waste all the water the pipe could pass; and when, from waste or other cause, it became insufficient for the business, larger pipes were furnished on application without extra charge. On the introduction of the Vartry water into the city, this was of necessity changed, and the manufacturers and large consumers have been charged by meter. At first, considerable resistance was made to the alteration, and the waste discovered in some establishments was enormous, the consumer having, under the old system, no interest in economising the water, and maintaining the fittings in a perfect state. Matters, however, have gradually improved, and the result of the new system has been a large increase to the corporation rental from this source.

The prices charged by the corporation for Vartry water are as follows:—

All quantities under			500	gallons	.	.	.	12	pence per 1,000 gallons.
500	and under		1,000	„	.	.	.	11	„ „
1,000	„		5,000	„	.	.	.	10	„ „
5,000	„		7,500	„	.	.	.	9	„ „
7,500	„		10,000	„	.	.	.	8	„ „
10,000	„		20,000	„	.	.	.	7	„ „
20,000	„		25,000	„	.	.	.	6	„ „
25,000	„		75,000	„	.	.	.	5	„ „
75,000 gallons and upwards					.	.	.	4	„ „

The meters are of Siemens' pattern, and the cocks and taps are of the patterns patented by Messrs. Guest and Chrimes.

Lead pipes must be alloyed with 4 per cent. of tin, and the corporation allow no lead pipes, taps, cocks, or other such fittings to be used, unless made in conformity with their standard patterns as to quality of material, weight, and manufacture; and all cocks and taps, before being used, are brought to the corporation office, examined, and if approved, stamped with their brand and numbered, and the name of the manufacturer registered, and for each article so registered there is a charge of 1*d.* It has also been made compulsory on all parties in getting in new fittings to place a stop-cock on the pipe where it passes from the main under the footpath, so that the water can be turned off the house for repairs without in any way interfering with the street main, and this cock is protected by a metal cover leaded into a granite flag laid in the path. These covers are hinged, to allow access to the cock, and when parties are detected wasting water and delay taking measures to prevent it, the water is turned off, and a lock secured to the lid to prevent access till the fittings inside have been made watertight.

The corporation now supply water to the following townships outside the municipal boundary:—

Name of Township.	Area of Township.	Population by Census of 1871.	Valuation on which Rate for 1873 was struck.	Rate the Townships are bound to pay for Water on the Valuation.	Quantity of Water the Corporation are bound to give per head of Population.
	A. R. P.		£.	d.	
Pembroke . . .	1,489 3 17	20,982	78,784	3½	20 gallons.
Black Rock . . .	1,066 2 11	8,089	46,848	3½	,,
Kilmainham. . .	536 1 24	4,956	7,241	4	,,
Kingstown . . .	898 2 12	16,378	66,302	5½	,,
Bray	1,056 1 14	6,087	21,151	4	,,
Dalkey	570 3 3	2,584	11,736	4	,,
Killiney and Ballybrack	1,003 3 38	2,290	9,141	4	,,
Clontarf	1,292 0 39	3,442	13,751	4	,,

In the cases of the Pembroke, Blackrock, Kilmainham, and Clontarf townships, the corporation incurred no expense in connecting their mains with those laid by the townships, except the necessary branch pipes and valves, as their mains reached to or passed along the township boundaries.

In the case of Kingstown, the corporation had to lay a 15-inch main from the Stillorgan reservoir, which cost £6,660, but this is

made available for the supply of water to Dalkey, at an additional cost of £1,700. The line of pipe to supply Bray cost £1,944 1*s.* 8*d.*, and that for supplying Ballybrack and Killiney will cost about £800. All these mains can be utilised for affording supplies to districts outside the township boundaries. The townships have in every case to lay down the distributing pipes in their districts and to maintain them, the corporation only delivering the water in bulk at their boundary.

Having described the Dublin corporation waterworks, as now completed and supplying water to the city and all the extra-municipal townships contemplated by the promoters, it may be briefly stated that the total cost to the citizens has been £610,000 (see Table VI. in the Appendix, p. 43), including the old and new debts; and as the population supplied is 330,000, this amounts to about £1 16*s.* 6*d.* per head.

During the preparation of the working plans, and subsequently while the works were in progress, several alterations and additions were made, not included in the parliamentary plans or estimates, with the view of rendering the works more efficient and complete. Among the most important were, the enlargement and alteration in the bywash and tunnel at Roundwood reservoir, increasing the size of the main from Callow Hill to Stillorgan from 32 inches to 33 inches in diameter, nearly doubling the size of the Stillorgan reservoir, laying a double line of pipes between Stillorgan and Dublin, constructing filter beds, building the water tower and bridge at Roundwood reservoir, laying 48-inch and 33-inch sluicing pipes from the Roundwood reservoir, and several other minor works, altogether costing about £63,000.

The Paper is accompanied by a series of drawings and diagrams, from which Plates 17 and 18 have been compiled.

APPENDIX.

TABLE I.—ANALYSIS of the WATER of the River Vartry, townland of Roundwood, County Wicklow, by Dr. Apjohn, Professor of Chemistry to Trinity College, Dublin. The water was taken up on June 5th, 1855, at 2.30 P.M., at a depth of 6 inches below the surface. Received for experiment on June 6th, 1855.

Specific gravity.—1·00021.

Suspended matter.—A very small amount of minute flocculent particles.

Colour.—A very slight tinge of yellow.
Smell.—None.
Taste.—Scarcely perceptible of vegetable matter.
Acid in a very slight degree, but neutral after evaporation.

IMPERIAL GALLON. Precipitated by boiling.

Silex	·030	
Peroxide of iron	trace	
Carbonate of lime	·039	
Carbonate of magnesia	trace	
Organic matter	·121	
		·190
Peroxide of iron	trace	
Lime	·402	
Magnesia	·242	
Potash	·165	
Soda	·656	
Silex	·080	
Muriatic acid	·867	
Sulphuric acid	·226	
Organic matter	1·580	
		4·218
Total solid matter	..	4·408
Total saline matter	..	2·707
Total organic matter	..	1·701
Total saline matter precipitated by boiling	..	·069
„ „ „ not precipitated by boiling	..	2·638
Degree of hardness by soap test	..	1·3
Degree of hardness after boiling	..	1·2

TABLE II.

RAINFALL from the Year 1861 to 1870, inclusive, as registered by gauges located within the Catchment basin supplying the Dublin Corporation Waterworks.

1861.	Annacarter, 750 Feet above Sea.	Knocka-temple, 760 Feet above Sea.	Tithewer, 1,000 Feet above Sea.	Roundwood, 800 Feet above Sea.	Vartry Lodge, 720 Feet above Sea.
	inches.	inches.	inches.	inches.	inches.
January	5·59	7·45	6·11		
February	9·66	7·75	7·22		
March	9·15	3·80	3·09		
April	3·51	2·74	2·33		
May	2·27	0·76	0·70		
June	3·59	3·76	3·27		
July	8·27	7·60	6·80		
August	6·32	6·13	5·24		
September	6·79	5·04	4·88		
October	3·85	3·78	3·28		
November	6·18	6·29	5·60		
December	5·69	4·73	3·36		
Total	70·87	59·83	51·88		

RAINFALL—*continued.*

	Annacarter, 750 Feet above Sea.	Knocka-temple, 760 Feet above Sea.	Tithewer, 1,000 Feet above Sea.	Roundwood, 800 Feet above Sea.	Vartry Lodge, 720 Feet above Sea.
	inches.	inches.	inches.	inches.	inches.
1862.					
January . . .	12·64	10·89	9·97		
February . . .	3·02	2·85	2·12		
March	5·21	5·12	4·99		
April	4·58	4·20	4·14		
May	4·15	3·60	3·39		
June	5·18	5·01	4·52		
July	6·72	6·44	5·77		
August . . .	4·96	3·02	3·41		
September . .	4·49	4·01	4·07		
October . . .	4·76	3·74	3·24		
November . . .	4·93	4·56	4·09		
December . . .	6·80	5·46	5·61		
Total . . .	67·44	58·90	55·32		
1863.					
January . . .	7·97	6·90	7·06	6·76	
February . . .	1·19	0·88	0·91	0·96	
March	4·42	3·89	3·97	4·11	
April	1·26	1·06	0·81	1·00	
May	1·24	1·10	0·96	1·14	
June	3·17	2·51	2·65	2·69	
July	1·56	1·27	1·31	1·40	
August . . .	5·33	4·86	4·59	4·76	
September . .	5·04	5·57	4·70	4·59	
October . . .	8·84	9·22	9·04	9·20	
November . .	4·60	4·30	3·98	4·27	
December . . .	3·09	3·74	3·72	3·79	
Total . . .	47·71	44·30	43·70	44·67	
1864.					
January . . .	7·53	5·60	5·43	6·11	
February . . .	2·21	1·75	1·95	1·99	
March	5·64	5·14	5·90	5·49	
April	1·00	0·44	0·35	0·29	
May	0·28	0·58	0·54	0·75	
June	0·98	0·75	0·79	0·77	
July	1·35	1·00	1·17	1·53	
August . . .	2·00	1·83	1·62	1·58	
September . .	4·40	4·06	4·15	4·13	
October . . .	11·56	10·43	10·87	10·39	
November . . .	10·26	9·90	9·87	10·08	
December . . .	4·59	3·79	3·61	4·60	
Total . . .	51·80	45·27	46 25	47·71	

RAINFALL—*continued.*

	Annacarter, 750 Feet above Sea.	Knocka-temple, 760 Feet above Sea.	Tithewer, 1,000 Feet above Sea.	Roundwood, 800 Feet above Sea.	Vartry Lodge, 720 Feet above Sea.
	inches.	inches.	inches.	inches.	inches.
1865.					
January . . .	6·04	6·33	5·56	6·08	
February . . .	3·55	3·64	3·69	4·51	
March	3·36	2·86	2·76	3·09	
April	2·16	1·87	1·89	2·05	
May	5·54	5·34	5·10	5·33	
June	1·18	1·53	1·18	1·60	
July	3·80	4·50	1·92	2·17	
August . . .	4·90	4·74	4·40	3·95	
September . .	1·27	0·66	0·70	0·67	
October . . .	2·41	2·10	1·72	1·86	
November. . .	5·62	5·40	5·00	4·50	
December . . .	10·89	11·98	12·00	11·36	
Total . . .	50·72	50·95	45·92	47·17	
1866.					
January . . .	12·03	8·63	9·00	10·53	..
February . . .	4·87	2·25	3·91	2·87	3·44
March	8·09	2·84	6·17	5·83	7·98
April	4·83	2·06	4·93	4·69	5·19
May	1·45	1·38	1·64	1·68	1·78
June	7·84	4·85	6·30	6·74	5·79
July	1·40	1·21	1·03	0·77	0·86
August . . .	5·31	2·98	4·45	3·75	3·40
September. . .	4·49	5·00	6·15	5·44	6·01
October . . .	4·71	4·33	4·90	4·63	4·97
November . . .	4·03	3·08	2·63	3·27	2·95
December . . .	4·21	3·87	3·09	3·59	3·85
Total . . .	63·26	42·48	54·20	53·79	46·22
1867.					
January . . .	7·29	5·53	7·71	7·34	6·15
February . . .	5·05	4·32	3·45	3·61	4·18
March	7·57	4·32	7·41	8·44	5·66
April	4·86	4·16	4·04	4·49	4·23
May	7·22	7·35	7·30	6·80	7·57
June	1·15	1·06	1·27	1·09	1·11
July	2·89	4·67	2·91	1·39	6·59
August . . .	2·08	1·94	1·95	0·63	2·36
September. . .	3·41	3·23	3·40	3·11	3·72
October . . .	4·36	2·86	3·12	3·21	3·45
November . . .	1·47	1·35	1·50	0·95	1·52
December . . .	3·75	2·23	2·28	1·86	2·58
Total . . .	51·10	43·02	46·34	42·92	49·12

RAINFALL—*continued.*

	Annacarter, 750 Feet above Sea.	Knocka-temple, 760 Feet above Sea.	Tithewer, 1,000 Feet above Sea.	Roundwood, 800 Feet above Sea.	Vartry Lodge, 720 Feet above Sea.
	inches.	inches.	inches.	inches.	inches.
1868.					
January . . .	6·84	5·16	4·46	4·11	5·80
February . . .	3·74	2·89	2·56	3·31	2·63
March	3·30	3·49	2·91	4·10	3·64
April	3·45	3·33	3·36	3·53	3·52
May	2·32	2·48	2·55	2·55	2·63
June	2·37	1·60	1·76	1·86	2·00
July	1·53	1·27	1·11	1·53	2·68
August . . .	6·20	4·03	2·32	6·18	6·57
September. . .	9·59	12·16	9·50	10·01	10·54
October . . .	2·69	2·41	1·88	3·17	1·65
November. . .	6·03	3·96	5·06	4·83	5·43
December . . .	11·90	10·76	12·00	10·50	15·02
Total . . .	59·96	53·54	49·47	55·68	62·11
1869.					
January . . .	7 24	7·20	6·13	7·21	9·66
February . . .	3·84	4·33	2·90	3·20	3·60
March	4·51	4·06	2·65	3·92	4·08
April	2·69	2 53	2·23	2·65	2·42
May	8·84	9·54	9·29	9·76	9·43
June	1·00	1·21	1·28	0·93	1·01
July	1·34	1·08	1·04	1·24	1·35
August . . .	1·45	1·07	1·03	1 31	1·03
September. . .	6·50	6·65	6·51	5·97	6·47
October . . .	3·27	2·62	2·84	2·72	2·74
November. . .	3·63	2·72	2·93	3·25	2·66
December . . .	6·18	6·39	6·33	6·19	6·47
Total . . .	50·49	49·40	45·16	48·35	50·92
1870.					
January . . .	4·62	5·01	4·94	6·21	5·23
February . . .	4·71	4·30	3·44	4·40	5·57
March	9·29	7·01	6·47	6·68	6 38
April	1·01	0·66	0·58	0·53	0·74
May	4·18	3·86	3·64	3 40	4·09
June	0·96	0 72	0·64	0·87	0·68
July	0·80	0·61	0·72	0·69	0 59
August . . .	3·33	2·82	2·65	2·88	2·52
September. . .	3·05	2·72	2·98	2·76	2·89
October . . .	9·42	9·36	8·39	9·51	9·32
November . . .	2·74	2·99	3·02	3·02	3·16
December . . .	2·63	2·77	2·97	2·93	3·34
Total . . .	46·74	42·83	40 44	43·88	44·51

RAINFALL—*continued.*

	Annacarter, 750 Feet above Sea.	Knocka-temple, 760 Feet above Sea.	Tithewer, 1,000 Feet above Sea.	Roundwood, 800 Feet above Sea.	Vartry Lodge, 720 Feet above Sea.
1871.	inches.	inches.	inches.	inches.	inches.
January	7·23	5·80	5·92	6·62	6·11
February	6·82	5·45	5·05	5·89	7·30
March	2·75	3·25	2·80	2·67	3·18
April	7·51	5·12	5·00	4·92	5·10
May	0·43	0·46	0·43	0·53	0·45
June	3·70	2·92	3·50	3·27	4·04
July	6·68	4·66	6·32	6·26	6·85
August	3·97	2·14	2·66	2·31	2·56
September	7·87	5·84	7·24	7·77	6·74
October	4·64	3·31	4·98	4·65	5·82
November	3·93	3·47	2·34	3·56	3·55
December	2·44	2·57	2·28	3·14	3·28
Total	57·97	44·99	48·72	51·59	54·98
1872.					
January	8·08	7·92	7·17	8·22	6·80
February	9·76	7·82	7·60	6·71	8·67
March	8·75	7·42	5·50	6·88	6·07
April	6·49	5·41	4·13	5·00	4·79
May	3·57	3·54	3·27	3·38	2·55
June	4·36	4·30	4·19	4·15	3·24
July	1·70	0·84	1·34	1·49	1·88
August	6·52	5·17	5·87	5·12	3·83
September	4·40	3·07	3·70	3·21	2·57
October	7·85	6·88	5·69	6·78	4·48
November	7·50	6·60	6·00	7·30	6·58
December	11·78	10·65	11·00	11·00	11·17
Total	80·76	69·62	65·46	68·24	62·63
1873.					
January	4·03	4·01	5·04	6·08	6·75
February	3·35	3·80	3·50	3·66	1·41
March	6·32	4·75	6·35	4·55	4·92
April	0·96	0·50	0·80	0·90	0·83
May	1·84	1·67	1·75	1·10	1·13
June	2·07	1·68	2·15	1·70	1·74
July	5·50	3·92	3·50	3·15	3·68
August	6·46	4·01	6·30	6·21	4·67
September	4·78	2·57	1·92	2·64	2·61
October	5·23	3·64	3·24	4·83	3·27
November	5·02	4·72	4·59	5·80	4·36
December	1·33	0·64	0·70	1·33	0·44
Total	46·89	35·91	39·84	41·95	35·81

TABLE III.

NOTES on SINKING SHAFTS and the Time Occupied. The Shafts were numbered from the lower end upwards.

No. of Shaft.	Power used for Pumping and Washing.	Total depth of Shafts to bottom of the Pump.	When Commenced.	When fully Sunk.	Dimensions of Shaft.	Average Rate of Progress per Week.	How left after Tunnel was Completed.	Remarks.
		feet.			feet.	feet.		
1	Horse Gin	129	Jan. 1864	April, 1864	11×9	7·6	Filled up .	Rather soft rock, except near the bottom, and not much water.
2	Ditto . .	114	Jan. 1863	Jan. 1, 1863	8×8	6·0	Left open .	Ditto.
3	Ditto . .	186	Oct. 1863	July 12, 1864	11×9	4·9	Filled up .	Ditto.
4	Steam . .	174	Jan. 1863	Aug. 22, 1864	8×8	2·1	Left open .	Very hard rock and great quantity of water; progress much delayed from small diameter of shaft.
5	Ditto . .	156	Aug. 1863	Feb. 12, 1865	11×9	2·4	Filled up .	Very hard rock and much water; work stopped eight months waiting for engine power.
6	Ditto . .	153	Aug. 1863	Jan. 25, 1865	11×9	3·0	Ditto . .	Ditto ditto; delay of five months.
7	Ditto . .	147	Feb. 1863	Aug. 22, 1864	8×8	1·93	Left open .	Very hard rock and great quantity of water.
8	Horse Gin.	165	Aug. 1863	May 23, 1864	11×9	4·0	Filled up.	
9	Ditto . .	144	Nov. 1863	June 21, 1864	11×9	4·3	Ditto.	
10	Steam . .	111	Feb. 1863	Aug. 31, 1863	8×8	3·7	Left open.	
11	Ditto . .	105	March, 1863	April 13, 1864	8×8	3·4	Filled up .	Nothing done from April to December, 1863 —twenty-four weeks.

12	Horse Gin.	96	Nov.	1863	June 21, 1864	11×9	4·5	Ditto . .	Idle three months.
13	Steam . .	87	Nov.	1863	Dec. 16, 1863	8×8	2·3	Left open .	Ditto six weeks.
14	Horse Gin.	81	Dec.	1863	April 26, 1864	11×9	3·9	Filled up.	
15	Ditto . .	90	Feb.	1863	July 25, 1863	8×8	3·6	Left open.	
16	Ditto . .	90	Dec.	1863	May 16, 1864	11×9	3·6	Filled up.	
17	Ditto . .	93	Dec.	1863	April 14, 1864	11×9	5·0	Ditto.	
18	Steam . .	75	March,	1863	June 1, 1863	8×8	5·7	Left open .	Very soft rock for two-thirds of the depth.
19	Jack Pole .	75	Dec.	1863	April 1, 1864	11×9	4·4	Filled up.	
20	.. ..	78	Dec.	1863	May 23, 1864	11×9	3·3	Left open.	
21	.. ..	39	Feb.	1863	April 1, 1863	8×8	5·5	Filled up .	Ditto ditto.
	Total . .	2,388					82·13	or 3·91 feet	on average per week.

Cost.

	£	s.	d.
Miners' wages	8,642	7	5
Powder, steel, and candles	1,366	8	1
Timbering and sheds	1,199	0	0
Bankmen, carpenters, and pump repairs	930	0	0
Winding and pumping	3,056	0	0
	£15,193	15	6

TABLE IV.

Tunnel. Details of Boring.

The Down Heading is called No. 1, and the Up Heading No. 2.

When Heading Commenced.		Total Length down in each Heading.	Length between the Shafts.	Time when Headings were Commenced.	Time when Headings met.	Rate of Progress per Week.	Remarks.
In Shafts.	Headings Driven.	feet.	feet.			feet.	
	Open end at Callow Hill	505	699	Jan. 1863	March 6, 1865	4·3	
No. 1	No. 1	194		May, 1864		4·34	
	„ 2	339	509	May, 1864	March 18, 1865	3·51	
„ 2	„ 1	170		June, 1863		3·44	
	„ 2	417	807	June, 1863	July 1, 1866	2·26	Beaumont's boring machine worked in this heading for five months, but only excavates 12 feet.
„ 3	„ 1	390		July 25, 1864		3·84	
	„ 2	312	588	July 25, 1864	April 15, 1866	3·37	
„ 4	„ 1	276		Aug. 22, 1864		3·18	
	„ 2	421	703	Aug. 22, 1864	Aug. 7, 1866	4·12	
„ 5	„ 1	282		Jan. 25, 1865		3·52	Great spout of water issued from the rock about 30 yards from the shaft.
	„ 2	279	575	Jan. 25, 1865	Aug. 23, 1866	3·4	Lowe's boring machine given up in this heading.
„ 6	„ 1	296		Feb. 21, 1865		3·73	Lowe's machine while working bored 5·3 feet per week in this heading.
	„ 2	231	615	Feb. 21, 1865	June 21, 1866	3·32	
„ 7	„ 1	384		Sept. 14, 1864		4·18	
	„ 2	335	651	Sept. 14, 1864	April 18, 1866	4·03	
„ 8	„ 1	316		May 23, 1864		3·2	
	„ 2	298	606	May 23, 1864	Sept. 7, 1866	2·5	
„ 9	„ 1	308		June 21, 1864		2·68	
	„ 2	207	575	June 21, 1864	Nov. 15, 1865	2·83	
„ 10	„ 1	368		Sept. 28, 1863		2·31	

	No. 2	309	607	Sept. 28, 1863	Sept. 25, 1865	3·0	
No. 11	„ 1	298		Apr. 16, 1864		3·98	
	„ 2	311	599	Apr. 16, 1864	Sept. 18, 1863	4·2	
„ 12	„ 1	288		June 21, 1864		4·43	
	„ 2	257	602	June 21, 1864	July 12, 1866	3·50	No driving done for four months after shaft was sunk.
„ 13	„ 1	345		Apr. 26, 1864		4·2	
	„ 2	329	649	Apr. 26, 1864	Sept. 11, 1866	3·4	Ditto ditto.
„ 14	„ 1	320		Apr. 26, 1864		4·64	Ditto, for nearly twelve months.
	„ 2	213	610	Apr. 26, 1864	Dec. 15, 1864	6·45	Rock soft, and part lined with brick.
„ 15	„ 1	397		July 1, 1863		5·25	Ditto ditto.
	„ 2	359	612	July 1, 1863	July 8, 1865	3·45	
„ 16	„ 1	253		July 25, 1864		4·86	
	„ 2	186	572	July 25, 1864	Oct. 2, 1866	3·32	
„ 17	„ 1	386		Apr. 12, 1864		3·6	The latter half nearly pure quartz.
	„ 2	221	619	Apr. 12, 1864	Sept. 12, 1865	3·0	
„ 18	„ 1	398		June 1, 1863		3·34	
	„ 2	351	581	June 1, 1863	June 16, 1865	3·4	
„ 19	„ 1	230		Apr. 1, 1864		3·63	Soft rock, and had to be lined in parts.
	„ 2	337	601	Apr. 1, 1864	May 17, 1866	3·0	
„ 20	„ 1	264		Sept. 26, 1864		3·1	
	„ 2	135	615	Sept. 26, 1864	June 19, 1865	3·55	
„ 21	„ 1	480		Apr. 1, 1863		4·14	
	Total length	12,995	feet, or		Average work	154·5	per week, or
		4,331⅔	yards.			3·68	feet average per week for each of the 42 faces.

Cost.

	£	s.	d.
Bankmen, miners' wages, &c.	20,110	17	1
Powder-fuze, candles	4,602	13	1
Grinding and pumping	14,237	4	0
Repairs to machinery, G. rings, &c.	3,622	5	2
	£42,572	19	4

TABLE V.—Diameter and Thickness of the Mains, and the Pressure they are calculated to bear.

Diameter of Pipe.	Thickness of Pipe.	Proof Pressure equal to a Column of Water.	Per Square Inch.	Maximum Pressure to which Pipes will be subject in Work.
inches.	inch.	feet.	lbs.	feet.
33	$\frac{7}{8}$	360	156	180
,,	$\frac{15}{16}$	400	$173\frac{1}{2}$	200
,,	1	430	$186\frac{1}{2}$	216
,,	$1\frac{1}{16}$	470	204	234
,,	$1\frac{1}{8}$	500	217	250
,,	$1\frac{3}{16}$	540	234	270
,,	$1\frac{1}{4}$	580	$251\frac{3}{4}$	288
,,	$1\frac{5}{16}$	600	260	306
27	$\frac{3}{4}$	320	139	160
,,	$\frac{13}{16}$	350	152	176
,,	$\frac{14}{16}$	380	165	192
,,	$\frac{15}{16}$	400	$173\frac{1}{2}$	208
,,	1	450	195	224
,,	$1\frac{1}{16}$	480	208	240

TABLE VI.

The total cost of works has been as follows:

	£ s. d.	£ s. d.
Cost of works of all kinds complete outside the city boundary, including superintendent's house, lodges, planting, road-making, forming ground, &c.	.. ..	330,434 12 8
PURCHASE OF WATER RIGHTS, LANDS, AND COMPENSATION.		
Paid for Kingstown Waterworks Company's rights and powers	5,889 19 2	
Paid for Lord Meath's rights in the exclusive supply of the Liberty with water	6,314 19 3	
Paid for land and way leave for construction of works	28,812 19 8	
Paid riparian proprietors below our works for loss of water, &c., and including Mr. Tighe .	40,162 7 8	
		81,180 5 9
Paid engineer's staff, draughtsmen, inspectors, overseers, pipe-inspectors, puddle-peepers, &c.	13,978 5 10	
Paid engineers consulted on works, and as witnesses in arbitrations, records, &c. . .	4,954 15 11	
		18,933 1 9
Paid for Parliamentary costs (including those incurred in the Coyford scheme, Bill No. 2 and Royal Commission), and all law costs incurred up to August, 1870	.. ..	27,186 13 4
		457,734 15 6
Cost of works in extending and relaying the city pipeage, including street wells, &c., up to 1st January, 1871	.. ..	66,822 0 2
		524,556 13 8
Damages and costs paid for injuries to property, &c., by burst pipes	.. ..	1,100 0 0
		525,656 13 6
Cost of laying mains from the corporation works to the boundaries of the Bray, Kingstown, Dalkey, and Killiney, and Ballybrack townships	.. ..	12,000 0 0
		537,656 13 8
Debt due by corporation on the moneys borrowed in 1809, to lay new mains, build the old basins, &c.	.. ..	72,000 0 0
		609,656 13 8

Mr. R. Hassard asked permission, as the engineer by whom the Vartry scheme had been originated, to state the reasons which had guided him in the selection of that locality. He had paid a great deal of attention to the subject some years previously, as it was evident that when the agreement, between the corporation of Dublin and the canal companies, for the existing water supply terminated, a new system would have to be adopted. He believed that he investigated every locality from which the city could be supplied. To the south of Dublin there existed a high range of mountain land, the northern and western slopes of which were drained by the Liffey and the Dodder, and from those streams a large quantity of water might be obtained; but much of the ground was occupied by mills and manufactories, and there would have been a considerable interference with ornamental property. Besides a great portion of the upper part of this drainage area was covered by beds of dense peat, so that the water for a large portion of the year would have been highly coloured, while the existing supply had at least the merit of being colourless. This objection appeared so serious, that Mr. Hassard came to the conclusion, that if pure water for the supply of Dublin by gravitation was to be obtained, it would be necessary to seek for it in some locality not draining into the Dublin basin. It then occurred to him that, if the water could be derived from the eastern slopes of the hills, the current being reversed from thence by pipes or aqueduct to the metropolis, supplying *in transitu* the districts of Killiney, Bray, Dalkey, Kingstown, &c., it would be a desirable course of proceeding, as the revenue from those districts would more than counterbalance the extra cost involved. It was at first thought wild and chimerical; but public opinion respecting it had greatly changed. He did not desire to speak of his own personal connection with the project. No doubt others besides himself had had schemes, to which they had devoted much time, labour, and money, taken out of their hands, and carried out by others. As regarded any professional credit attaching to the engineer who devised the scheme, he certainly laid claim to it; and Mr. Neville was equally entitled to all the credit of carrying out the works to a successful issue.

Mr. Beloe said, having had considerable experience in such matters, as Chairman of the Liverpool Waterworks for many years, he thought great credit was due to those who had carried out the Dublin works, for the financial results of the undertaking. He was greatly suprised to hear that the total cost of the works was only £607,000. They were nearly of the same magni-

tude as those at Liverpool, which had cost about £2,000,000. He had been struck with the wonderful talent with which the engineer had managed to buy up all the compensation water that would otherwise have had to go to various owners. In Liverpool they had a few years ago to deliver no less than 70,000,000 gallons weekly as compensation, which was useless to those who received it, while the loss was a great detriment to the town of Liverpool. He had never seen any works so complete and so efficient as those at Dublin.

Mr. S. C. Homersham said he supposed there was some reason for screening the water after it was filtered. It appeared to him that if the pure water basins, after the water was filtered, had been covered, and if the service reservoirs near the town had been covered, there would have been no need for screening. The water would then have been delivered in a much better condition than by being collected after filtration in open reservoirs near to the source, and subsequently left in open reservoirs near to the town, and then screened. With regard to the relative cost of the Dublin and the Liverpool works, the elements of comparison were not the same. No doubt a large amount of compensation had been given to millowners, and the purchase of the riparian rights upon the streams at Liverpool had cost an enormous sum, in addition to which the old works in the hands of private companies had to be bought up. The Dublin works, he believed, had been in the hands of the corporation from time immemorial, so that the interests of old companies had not to be purchased.

Mr. Beloe said the cost of the Rivington works was about £1,500,000; but that did not represent the entire cost, for they had had to pay for other works besides. The compensation to which he alluded was compensation in water, and not in money.

Mr. Homersham said the reservoirs must be made of sufficient capacity to give the compensation in water, and that involved a money expenditure.

Mr. Vignoles, Past President, said Mr. Beloe would be doing good service if he would distinguish the mere cost of the water supply from the various collateral expenses, particularly the compensation in the several forms of money, works, and water. It was impossible to institute a fair comparison between the Liverpool and the Dublin works without knowing the various circumstances of the case.

Mr. G. J. Symons said there was one lesson that might be gathered from the Paper. He did not desire to go into a long disquisition as to the history of the Dublin Corporation Waterworks

and their connection with rainfall; but that connection was very intimate, and he believed would prove to be extremely instructive. When the works were laid out, the only data as to the quantity of water that could be gathered on the hills consisted of two sets of observations, one set made by the Royal Engineers at their office in Phœnix Park, and another set made at a station called Fassaroe, the fall being much larger at the latter station than at Dublin. When the Vartry scheme was brought forward it was attacked on the ground that the Fassaroe gauge was not to be trusted. There was considerable discussion on the subject. On the one hand it was said that Fassaroe, if anything, showed too little; that inasmuch as it was at an elevation of only 200 feet, and much of the gathering-ground was considerably higher, it was necessary to add a certain percentage to the Fassaroe values. On the other hand, it was contended that the Fassaroe gauge was not to be trusted at all, and that the only thing to do was to take the Dublin gauge with some slight increase. That, he believed, speaking from memory, was taken at 28 inches or 29 inches, while Fassaroe was 35 inches. It appeared that a series of observations had now been taken over several years, and a result obtained such as might have been anticipated. The plateau on the eastern side of the range of hills was the very place where the largest rainfall might be expected. It was not usually obtained on the south-west side, where the wind came driving up; but when the air had been cooled by rising to a considerable height, and by the coolness of the ground over which it had passed its capacity for holding water was diminished, the rain fell. He had been much astonished at some of the views enunciated on the subject when the scheme was before Parliament in 1861. The results already obtained showed that it was not wise, when a rain gauge gave a result not exactly agreeing with one's desires and expectation, forthwith to conclude that it was wrong. It was also shown that it was possible, by calculation and observation of the fall at a low level, to make a fair approximation to what the result would be at a higher level in the same neighbourhood.

Mr. A. R. Binnie thought some explanation should be given as to the reason for filtration. It was stated that the Dublin water was equal in quality to that of Glasgow, obtained from Lake Katrine, which, as was well known, did not require filtration; but the analyses in the Paper showed that it was of a less pure quality. The account of the difficulties and dangers experienced in consequence of the leakage through the culvert, showed the care that should always be taken in constructing outlet works. Had a tunnel been

driven through solid rock, without interfering with or underlying the embankment, he thought the danger would not have existed.

Mr. Telford Simpson said the works could not now, owing to the rise in price of material and labour, be constructed for less than £800,000. He had understood that the Liverpool works had cost considerably more than £2,000,000, probably, including all expenses, about £3,000,000. But the circumstances were very different in the two cases. The Vartry scheme was almost entirely a new one. He believed the cost of the original works of the Dublin Corporation were not included in the £600,000. In that case it would only be fair to add another £200,000 or £300,000, making in all £900,000. Then the population of Liverpool was 500,000, while that of Dublin was only 300,000. These circumstances would bring the figures somewhat nearer, but still there was a large discrepancy, and the Liverpool works might be considered as having cost twice as much as those at Dublin. But the former had been added to and patched up from time to time, which was always a more costly process than carrying out an entirely new scheme on a large scale.

Mr. Alexander Fraser asked if there had been any appreciable effect upon the health of the population of Dublin in consequence of the substitution of soft water for the previous supply of hard water, which had been provided for many years. He supposed, from the small area of the filter beds, that the water was almost of uniform quality, and that the district was not subject to floods, or to any cause that would make the water thicker at one time than at another. He observed, however, that larger filter beds were about to be provided.

Dr. Pole expressed regret that more information was not given respecting the distribution of the water in the city. He had endeavoured to make out the quantity consumed per head. He found that the total quantity of water was recorded; but as there was no information as to the population actually supplied, it was not possible to calculate the quantity per individual. There was, however, reason to think that the consumption within the city was large, probably amounting to 40, or more, gallons per head per diem. The question of distribution of water in large towns, under the constant supply system, was at present one of the most important problems in regard to water supply; and it had an especial interest, owing to what had lately taken place in regard to the metropolis. There had been much discussion as to the introduction of constant supply into London Laws had been passed and official regulations had been drawn up; and although nothing had been practically done, the question only slept, and would soon

be revived. The difficulty was, how to introduce constant supply with the least possible inconvenience to the inhabitants, and yet without incurring unnecessary loss to the companies by waste of water. The experience in large towns was very discordant; in some, as in Manchester and in Norwich, the change had been effected with economy and success; while in others, as in Glasgow and in Liverpool, the waste was excessive. Hence it was important to get the results of experience gained in all large towns where a change of system had been introduced. It was probable that the waste or economy of water largely depended on the nature of the rules and regulations adopted for the distribution, and on the degree of stringency with which they were enforced. Hence he conceived information on these points in regard to Dublin would be of much utility, not only to the profession, but to the public at large.

Mr. Rogers Field said, when the question was discussed before Parliament in 1861, it was stated by the opponents of the measure that the loss of water by evaporation and absorption would be much larger than in ordinary hill districts, on account of the peculiar formation of the ground, the contention being that it was not really a hill district, but a large plateau. It appeared that the water had been gauged regularly, and it would be interesting to know not only the rainfall but the amount of water that had run off. It was stated in 1861 that the loss by absorption and evaporation would be something like 18 inches; while in the Paper the loss was given as 15 inches, but it was not clear whether this was the actual measured amount, or merely an estimate. The Author said his experiment proved that the quantity of water calculated by the usual formula for the flow of water over weirs was larger than the amount actually discharged. It would be interesting to know what was meant by the usual formula, seeing that there were a number of different formulæ applicable to different cases. It was also stated that the 33-inch main discharged a larger quantity than was calculated. He should be glad to know whether it had continued to discharge that quantity. It was a well-ascertained fact that large mains discharged a greater amount than that given by the usual formula, but he believed in most cases it was found that the amount gradually fell off. This had been the case with the 48-inch pipes in the Glasgow works. In the first instance the amount was something like 50 per cent. larger than that given by Eytelwein's formula, but it gradually diminished, though the pipes still continued to discharge more than the amount given by the formula.

Sir JOHN COODE said he was connected, though not professionally, with the case of a small town where the waterworks were laid out by Mr. Hawksley; the pressure was about 200 feet, and the consumption in the first year was about 9 gallons per head per day. The service, which was constant, was entirely new throughout the town, and the smallness of the quantity consumed was owing to the absence of waste—a result due to the stringent regulations adopted with regard to the service-pipes. No plumber who was not on the Company's list was allowed to be employed.

Mr. HASSARD, in replying for the Author, said, with regard to the necessity for filtration, there was no analogy between Loch Katrine and the Vartry Basin. Loch Katrine had a drainage area of 22,000 acres, and the water surface was 3,000 acres, or $\frac{1}{7}$th of the total drainage area. Vartry had a drainage area of 14,000 acres, and a water surface of 400 acres, or $\frac{1}{35}$th of the drainage area. When the Vartry scheme was first projected a flood water-course was proposed, by which the dirty water brought down in a flood could be shut off from the reservoir; but a doubt arising as to the amount of the rainfall the corporation thought it best to impound all the water, and, if necesssary, to construct filters. That was thought to be the safest course. The area of the filters was not unusually small. They were designed according to the usual rate of 700 gallons per day for every square yard of filtering surface. The cost of the works, £610,000, included every expenditure,—£72,000 for the old works, £66,000 for laying new mains, and also the amount expended in application to Parliament for other schemes. The population supplied was 300,000, excluding the township of Rathmines. The daily consumption was 45 gallons per head. The distribution was constant. The large consumption was no doubt due to the circumstance of a new supply being brought in at a high pressure where only old fittings existed. In another town in Ireland, where he had constructed waterworks under similar conditions, there had been a comparatively low pressure for many years, and when the water was brought in at a pressure of 190 feet, almost every house service-pipe in the town had to be renewed. The 33-inch pipes in Dublin continued to deliver 18,000,000 gallons daily until the consumption was somewhat checked. With regard to the effect of the change upon the health of the population, he could only say that every one was loud in its praise; it was simply substituting pure for impure water; and if any evil effects had arisen, something would have been heard of them.

March 3, 1874.

THOMAS E. HARRISON, President,
in the Chair.

The following candidates were balloted for and duly elected:—Alfred Walter Brind, Arthur Harman M°Donald, and James Alkin Paskin, as Members; Robert Ballard, Oswald Brown, Stud. Inst. C.E., Thomas Duerdin, Stud. Inst. C.E., Malcolm Graham, Stud. Inst. C.E., George Gatton Melhuish Hardingham, Stud. Inst. C.E., Lieut.-Col. Charles Scrope Hutchinson, R.E., Samuel Hubbard James, Hugo Leupold, Michael Longridge, Francis Blayney Maclaran, John Coombe Searle, Stud. Inst. C.E., Charles Woodley Whitaker, and Arthur Woods, as Associates.

It was announced that the Council, acting under the provisions of Sect. III., Cl. 7, of the Bye-Laws, had transferred Joseph Gordon and Joseph Tomlinson, jun., from the class of Associate to that of Member.

Also, that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—John Edward Catton, William Patrick Churchward, Hampden Henry Hely, William Henry Jones, William Gibbs Kerle, Josiah Edward Paul, and William Pole, jun.

No. 1,394.—"The Great Basses Lighthouse, Ceylon." By William Douglass, M. Inst. C.E.

In consequence of the vast increase in the shipping, especially steamers, passing the south-east coast of Ceylon, the subject of lighthouses, for marking its outlying dangers, received for many years the consideration of the colonial authorities. As early as November 1826 an examination was made of the south and east coasts of the island by the late Sir J. J. Gordon Bremer, when in command of Her Majesty's ship 'Tamar,' and the late Captain W. F. Dawson, of the Royal Engineers, for the purpose of ascertaining the most eligible positions for lighthouses or beacons.

The result was a recommendation that lighthouses should be erected on Dondra Head, and on Flagstaff Point, Trincomalie, and a beacon on the Great Basses; and that a light-vessel should be moored near the Little Basses. (Plate 19.)

In 1853 a survey was made of the Great and Little Basses by Rear-Admiral Sir W. H. Hall, K.C.B., who recommended the erection of a lighthouse on the Great Basses, and the mooring of a light-vessel near the Little Basses. Admiral Pellew, then Commander-in-Chief at Trincomalie, in a report to the Secretary of the Admiralty, dated May 16th, 1853, stated that "There are now about ten large steamers monthly touching at Galle, all of which have to pass the Basses, and mostly during the night; and if left unlighted, some serious accident may be expected to occur." These recommendations were afterwards confirmed by the late Admiral Sir Francis Beaufort (Hydrographer to the Admiralty), who suggested the immediate construction of the lighthouse on the Great Basses, but considered that the placing of a light-vessel, to mark the Little Basses, might be suspended, until the lighthouse on the Great Basses was in progress. The most eligible anchorage for such a vessel should then, he said, be carefully sought, and the extent and nature of the reef closely examined, as possibly it might be found to afford a spot sufficiently wide and stable to support a tower.

On the 16th of July, 1855, the late Mr. Alexander Gordon, M. Inst. C.E., was instructed by the Board of Trade to prepare and submit plans and estimates for a lighthouse on the Great Basses, and to consider the relative expense and advantages of stone and iron as materials for constructing the same. The design submitted and recommended by Mr. Gordon is shown on Plate 20. It was a cylindrical cast-iron tower, secured within an enlarged basement of masonry or brickwork. The basement was inclosed within an outer casing of cast iron 2 inches thick, and both the tower and the casing were sunk into the rock. The basement was to be 30 feet in height above the rock. The brickwork inside the cast-iron casing was to be set in bitumen, worked hot, and bonded to the outer shell. In order to prevent salt water remaining in contact with the cast-iron shell at its junction with the rock, it was proposed to provide an outer inclosing ring or plinth, about 2 feet high, leaving an annular space about 1 foot wide between the plinth and the casing of the basement, which space was to be filled with heated Trinidad pitch, mixed with sand and small gravel. As each course of plates of the basement and portion of tower within it was laid and bolted together, the

interior was to be filled up to the same level by large Ceylon bricks, 12 inches by 6 inches by 4 inches, set and jointed solid in Trinidad pitch, mixed with an equal quantity of sharp sand, and applied hot. The inside and outside of the ironwork were to be well "paid" over with the same, and the space between the iron and the brickwork was to be carefully run-in at every course of bricks with the same hot bituminous mixture. Accommodation for the light-keepers was to be provided in and upon the basement, the plateau of which could be covered at pleasure by an awning. The cast-iron shaft, 12 feet in diameter, built of plates 1 inch thick, and lined with thin wrought iron, secured to the internal flanges, was to be surmounted by a lantern and apparatus for a revolving catoptric light at an elevation of 120 feet above high-water. The illuminating apparatus, consisting of eighteen paraboloidal 'Gordon' reflectors, each 21 inches in diameter, was arranged in six faces of three reflectors to each face, thus giving six beams of light to the circle. The total cost of the work, including the necessary station on shore, was estimated at £15,673 15*s.*, and it was considered that the work could be completed, and the light exhibited, in about eighteen months.

An alternative plan, with the basement constructed of pick-dressed granite, was ultimately determined on by the Board of Trade, which occasioned an increase of £4,000 in the estimate. Mr. Gordon thought that the work, thus modified, would be completed within six years. It was resolved to employ a steamer in lieu of sailing-vessels, as previously intended. A revised estimate, embodying these additions, and amounting to £33,946, was submitted and finally approved.

On the 20th of March, 1856, the late Mr. W. W. Poingdestre, Assoc. Inst. C.E., having been appointed Resident Engineer, left England for Ceylon, to carry on the operations. In the meantime the granite base, iron tower, lantern, and illuminating apparatus were prepared in England and despatched to Galle, where they were landed and stored. After three years only a few landings at the rock had been effected, and nothing had been accomplished beyond the erection of a beacon-mast, 60 feet high, surmounted by a ball, and the marking-out of the site of the proposed lighthouse. It was found, in fact, that the difficulties had not been fully appreciated before the work was commenced, and consequently the arrangements for meeting them proved insufficient. According to Parliamentary Paper No. 491, session 1863, page 138, about £40,000 had been expended, and it was estimated that £20,000 per annum for five years would still be required to complete the

lighthouse. The authorities, unwilling to enter into so large an expenditure upon what seemed, from past experience, a doubtful chance of success, suffered the work to lie in abeyance.

Various schemes were subsequently submitted to the Board of Trade for the erection of a lighthouse on the Great Basses, of which one, apparently the most deserving of consideration, was from Colonel Fraser, R.E., C.B., who had previously erected the lighthouse on the Alguada Reef, in the Bay of Bengal, under circumstances of great difficulty. Colonel Fraser proposed to erect a granite structure, having a base 15½ feet high, with its bottom course 33 feet in diameter, and on this base to place the granite pedestal of Mr. Gordon's lighthouse, which was in turn to be surmounted by a granite tower, 74½ feet high. Colonel Fraser's estimate for the work, exclusive of the lantern, of the illuminating apparatus, and of the value of the materials already provided for the original structure, then lying at Galle, was £53,914.

In June 1867 the whole question as to the practicability, probable cost, and reasonable chance of success of the erection of a lighthouse on the Great Basses, together with the various proposals for its construction, was referred to the Elder Brethren of the Trinity House, and the result was the design by their Engineer, Mr. J. N. Douglass, M. Inst. C.E., shown on Plate 21.

This design was for a granite structure, in which the base of the 'Gordon' lighthouse, the only portion of the original work which could be made available, was proposed to be utilised, as previously suggested by Colonel Fraser. The plan further included a lantern and dioptric revolving apparatus of the first order, also a light-vessel, to be moored off the rock, for exhibiting a red revolving light regularly every night, from the commencement to the completion of the work, and to serve as a barrack for the executive engineer and staff. The total estimated cost of the work was £64,661.

A double advantage was anticipated from the barrack light-ship: the working party would be accommodated, and the Government would be enabled at once to collect a toll for the light, instead of waiting for the completion of the tower. The Board of Trade, having approved the design, and having requested the Trinity House to undertake the execution of the work, the necessary funds were voted by Parliament, and the work was immediately proceeded with. The Author, who was then building the Wolf Rock lighthouse, was appointed Executive Engineer. Two iron twin-screw steam vessels, and the light-

vessel, all specially designed for the work, together with the granite tower, internal fittings and lantern, and the dioptric illuminating apparatus, were put in hand, the contracts for the several works being taken by various firms as follows, viz.:— Iron steam vessels, Messrs. T. B. Seath and Co., Glasgow; light-vessel and floating barrack, Messrs. Fletcher, Son, and Fearnall, Limehouse; illuminating apparatus for this vessel, Messrs. Wilkins and Co., Long Acre; granite tower, Messrs. Shearer, Smith, and Co., Dalbeattie, Scotland; lantern and internal fittings of tower, Messrs. Deville and Co., London; dioptric illuminating apparatus, Messrs. Chance, Brothers, and Co., Birmingham. The present lighthouse consists of a cylindrical base, 30 feet in height and 32 feet in diameter, on which is placed a tower, 67 feet 5 inches in height, 23 feet in diameter at the base, and 17 feet in diameter at the springing of the curve of the cavetto. The thickness of the wall at the base of the tower is 5 feet, and at the top 2 feet. The accommodation within consists of six circular rooms, each 13 feet in diameter. There is also a room in the base 12 feet in diameter for coals and water, and a rain-water tank below 7 feet 6 inches in diameter. From the floor of the tank to the rock, a depth of 11 feet 6 inches, the building is solid. The tower contains 12,288 cubic feet of granite, and the cylindrical base 25,077 cubic feet, making a total of 37,365 cubic feet, weighing about 2,768 tons.

The stones forming the wall of the tower are dovetailed, both horizontally and vertically, in the same manner as was adopted at the Wolf Rock lighthouse. Each course of the base was at first only joggled horizontally with granite joggles, the courses having no bond with those either above or below them. Slate joggles, 6 inches longer than the granite joggles at first provided, have been substituted, and holes, 3 inches deep, have been cut in the courses above and below to receive the ends of each joggle, thereby obtaining a horizontal bond between each course of twice the total sectional area of the joggles. Bolting was not required, as the sea did not break over the rock during the working season with sufficient force to displace the stones when set.

Medina cement was used for the first and second courses, and Portland cement for the courses above. Salt water was employed for mixing the cement for the base, and fresh water for the cement above the base. The cement was mixed with an equal portion of clean, sharp, river sand for bedding the stones above the base; and the joints were filled with pure cement. The step ladders, for ascending from floor to floor, are of cast iron. The entrance door

and storm shutters are of gun metal. The cylindrical 14-feet lantern of the Trinity House was adopted. The dioptric apparatus has eight panels of refractors, with upper and lower prisms, for emitting flashes of red light at intervals of forty-five seconds; the colour being produced at the glass chimney on the large central lamp, which chimney is ruby-coloured.

A 5-cwt. bell, for a signal during foggy weather, is fixed on the lantern gallery. It is struck three blows in quick succession, every fifteen seconds, by two hammers worked from machinery fixed in the pedestal of the dioptric apparatus.

The Great Basses reef is 80 miles to the eastward of Point de Galle, and 6 miles from the nearest land, viz., Kirinde. It is about $\frac{5}{8}$ mile long, $\frac{1}{4}$ mile broad, and is composed of hard red sandstone. Four rocks are above water, and two are just a-wash. The lighthouse is built on the east rock, which is 220 feet in length, 75 feet in breadth, and 6 feet above the mean sea level. The extreme range of tide is about 3 feet. The reef is exposed to both monsoons, therefore the days available for working on it are few. If 50 miles nearer Galle, or the same distance nearer Trincomalie, the number of days when work might be executed on it during a monsoon would be doubled. The only suitable season for working on the rock is during the north-east monsoon, which commences in November and terminates in April; and the best months of the monsoon are the first and the last two. During part of December, the whole of January, and part of February, the wind blows strongly from the N.E., especially about 2 P.M., when a short quick sea, on reaching the shallow water near the reef, breaks heavily on each side, rendering it dangerous to approach the rocks in a boat. During November, March, and April the wind is variable; light breezes prevail frequently off the shore in the morning, and on the shore in the evening, with a calm at mid-day. The current sets westward during the north-east monsoon, and eastward during the south-west monsoon; the speed is very irregular, sometimes varying from $\frac{1}{2}$ knot to 4 knots per hour during the same day. The usual direction of the current is parallel with the coast, and at the Great Basses it changes very little from this course. Towards the close of the monsoon the current is weak, and occasionally flows feebly in opposite directions during the same day. It attains the highest velocity to the westward in December, January, and the early part of February.

The coast for many miles on both sides of the Basses is almost continuously exposed to a heavy surf from S. or S.W. As it is

very thinly populated, and without secure shelter for shipping, it was determined to form at Galle the depôt, from which the operations at the rock were to be carried on.

Two iron twin-screw steamers, one of which is shown on Plate 22, each capable of carrying 120 tons of cargo at a speed of 10 knots per hour, were used for conveying the materials from the workyard at Galle to the rock, and for attending upon the light-vessel and floating barrack, as well as the Little Basses light-vessel, during the progress of the work. For the purpose of landing and hoisting material rapidly at the rock with a minimum number of workmen, the steamers were each fitted with two steam double-barrel winches, by which the stones of the tower were hoisted on board, stowed below, hoisted again to the deck, and from thence to the rock. The Author is of opinion that this is the first instance of material being landed in a seaway from a vessel by means of her own steam-power, excepting where the load could be deposited by her own swinging derrick. The arrangement was very successful, and tended considerably to expedite the completion of the work. Although it was necessary, owing to the shallow water, to moor the steamers, when laden, at a distance of 30 fathoms from the rock, stones weighing on an average $2\frac{1}{2}$ tons were hoisted out of the hold, landed, and deposited 28 feet above the rock, at the rate of ten per hour.

On the 8th of November, 1869, the Author left England, and on the 14th of the following month arrived at Galle. On the 27th of the same month he made an attempt to reach the Basses in a small sailing vessel, but, owing to head winds and an adverse current, only one-third of the distance was reached in eight days. He therefore returned to Galle to await the arrival from England of one of the steamers, the 'Arrow,' which, under the command of Captain Laing, of the Peninsular and Oriental Company, reached Galle on the 27th of February 1870, *viâ* the Suez Canal. Her cargo of plant and stores was immediately discharged, and her hold was fitted up to accommodate native workmen. On the 5th of March she left for the Great Basses; and on the 7th the Author landed on the rock, when he determined on the site for the lighthouse.

The excavation of the foundation for the previous work was scarcely visible. There was a timber beacon pole on the rock, surmounted by a small ball; the stays of coir rope, which had been attached to the mast and eye-bolts fixed in the rock, had parted; but the mast, being well stepped in the rock, remained upright. Chain-stays were at once fitted to the mast, and a long derrick was

suspended from it, which derrick, with the aid of a small winch, served for landing cement and sand. To prevent the almost constant wash of the sea interfering with and delaying the cutting of the foundation for the tower, advantage was taken of every opportunity to build, in quick-setting Medina cement, a brick dam, 2 feet thick and 3 feet high, round the seaward side of the foundation. To this the rubble stone excavated from the foundation was added, until a continuous wall or dam was formed, 3 feet 6 inches thick and 4 feet 6 inches high, provided with holes for drainage. This dam afforded protection from the surf for the workmen while engaged trimming the foundation pit. It has since been faced with small ashlar and coped, and now forms a useful portion of the landing platform,—also constructed of rubble stone in cement, and faced and coped with granite ashlar. This platform contains 10,443 cubic feet of masonry, making, together with the tower and base, a total of 47,808 cubic feet, or about 3,541 tons. The foundation-pit was roughly excavated by means of small charges of powder, carefully applied, so as not to shake the rock; and the surface was afterwards finished with pick and point.

On the 17th of March, 1870, the light-vessel arrived at Galle from London, *viâ* the Cape. On the 30th of the same month, the vessel was moored $\frac{1}{3}$ mile E.N.E. of the reef, and the light was exhibited the same evening. The workmen were now quartered on board the light-vessel, and the 'Arrow' was available to obtain supplies from Galle without delaying the work.

The season ended on the 3rd of May, when thirty-six landings had been effected and two hundred and twenty hours worked on the rock. In this time the foundation-pit was prepared, the dam was completed around the foundation, and part of the landing platform had been built with the stone excavated.

Season of 1870—1871.

On the 19th of October, 1870, the 'Hercules,' under the command of Captain Laing, arrived at Galle from London, *viâ* the Suez Canal, to co-operate with the 'Arrow' in conveying material from Galle to the rock. The first landing for the season took place on the 28th of November, and the last on the 28th of April. Eighty-four landings were effected, and six hundred and fifty-one hours worked on the rock. The first stone was landed on the 28th of December, after which both vessels were used alternately in conveying stone from Galle to the rock. During the monsoon the foundation was completed, and sixteen stones of the twenty-

first course were set. The dam around the foundation was also faced with ashlar, and coped.

Season of 1871—1872.

The first landing took place on the 16th of November, and the last on the 2nd of May. During the season seventy-four landings were effected, and six hundred and seventy-nine hours worked on the rock. A hurricane-house was fixed on the gallery around the base of the tower, to afford extra accommodation for the workmen when remaining on the rock, and in it a steam winch, for hoisting the stones to the top of the work, was fixed. The remaining portion of the masonry of the tower from the twenty-first course was set, and the framing of the lantern erected.

The number of working days of ten hours, from the first landing on the rock to the end of this season, was one hundred and fifty-five days three hours; and from laying the first stone of the tower to setting the last stone of the gallery course, one hundred and ten days.

Method of landing the Stones of the Tower.

(Plate 23.)

A strong spar, 45 feet long and 14 inches diameter, was stepped into the rock 3 feet. To this spar three $\frac{5}{8}$-inch chain-guys were fixed, and from it a derrick, 50 feet long and 14 inches diameter at the centre, was swung by a $\frac{3}{4}$-inch chain, 20 feet long. A chain-guy was fixed to the head of the derrick, the latter being worked by a small winch, controlled by one man. The leading block at the foot of the derrick was so placed as to allow the derrick to travel inwards freely, the winch being used to ease it to the proper position.

The steamer in attendance was moored, one anchor ahead and a 4-inch warp to the mooring buoy, for veering it into position; two 11-inch coir hawsers were abreast to the mooring buoys, and two 8-inch coir hawsers to the rock.

The holds of the steamboats were fitted with two tiers of rollers, on which the stones were placed, and by means of which they were brought speedily under the hatchways, where an iron cage, working in slides, was fitted for conveying them to the level of the deck. The vessels, as already mentioned, were each provided with two strong double-barrel steam winches, either barrel of each winch working separately if required. Between the hatchway and the gangway a frame, carrying rollers, was fixed, to facilitate the pas-

sage of the stones over the side. One barrel of the forward winch lifted the stone on deck and deposited it on the rollers, in readiness to go out of the gangway. The shore purchase consisted of three parts of $\frac{1}{2}$-inch chain, one end of which chain was made fast to the head of the rock derrick; the other end, after passing through a block at the foot of the derrick, and thence on board to the end of the winch aft, was made fast to the stone. A $\frac{7}{16}$-inch guy-chain was also attached to the stone and No. 2 barrel of the forward winch, on which was a powerful break. The winch aft was put in motion, and, as the stone went over the side, the guy-chain was eased away until the stone entered the water. It was then gradually checked, and "paid" out at about the same speed as the winch aft worked the stone ashore, until it hung perpendicularly from the rock derrick. When the stone was high enough, the derrick was swung towards the tower to its proper position by means of the small winch on shore, and the stone was then lowered. After the stone was released, No. 2 barrel of the forward winch was put in motion, and the purchase hove-off for another stone.

For depositing the stones gently on the tower during rough weather a strong tackle, with a claw attached to the top, was fixed at the foot of the derrick, and when the stone was at its full height, the claw was slipped on to the chain of the lifting purchase; the winch was then promptly reversed, and the stone was afterwards lowered by means of the tackle. A second tackle was attached to the derrick mast, with a claw at the bottom, for the purpose of taking up sufficient slack chain after the stone was lowered, to allow the lifting purchase to be released. One man attended to both tackles.

TOTAL NUMBER OF HOURS WORKED ON THE ROCK.

	hours.	mins.		days of 10 hours.	hours.	mins.
First Season: March 7th to May 3rd, 1870—						
	222	42	=	22	2	42
Second Season: Nov. 28th, 1870, to April 28th, 1871—						
	651	39	=	65	1	39
Third Season: Nov. 16th, 1871, to May 2nd, 1872—						
	678	59	=	67	8	59
Total	1,553	20	=	155	3	20

The number of hours worked on the rock from the first time of landing (March 7th, 1870) to the date of setting the last stone (April 10th, 1872) was—

hours.	mins.		days.	hours.	mins.
1,422	17	=	142	2	17

The number of hours from the date of setting the first stone (Dec. 28th, 1870) to the date of setting the last stone (April 10th, 1872) was—

hours.	mins.		days.	hours.	mins.
1,100	55	=	110	0	55

The number of hours cutting out the foundation, building the dam, and rigging the gear was—

First Season: March 7th to May 3rd, 1870—

	hours.	mins.		days.	hours.	mins.
	222	42	=	22	2	42

Part of second season, Nov. 28th to Dec. 27th, 1870—

	98	40	=	9	8	40
Total	321	22	=	32	1	22

The number of landings on the rock was—

First Season, 1870	36
Second Season, 1870 and 1871 .	84
Third Season, 1871 and 1872 . .	74
Total	194

The maximum and minimum number of hours worked on the rock—

	hours.	mins.
Maximum . . .	11	17
Minimum . . .	1	47

Description and Number of Persons employed at the Work.

1 executive engineer, 1 chief foreman of works, 1 accountant and storekeeper.

'*Arrow*,' *S.V.*—(Europeans) 1 master, 1 mate, 2 engineers, 1 stoker, 2 seamen; (natives) 1 serang, 6 lascars, 1 bandaddy, 3 firemen, 1 cook, 1 steward.

'*Hercules*,' *S.V.*—(Europeans) 1 master, 1 mate, 2 engineers, 2 stokers, 2 seamen, 1 boy; (natives) 1 serang, 6 lascars, 1 bandaddy, 2 firemen, 1 cook, 1 steward.

Light-Vessel.—(Europeans) 1 master, 1 mate; (natives) 1 serang, 6 lascars, 1 bandaddy, 1 cook, 3 lamp-trimmers.

During the working season at the rock the following were added, viz.: 1 lascar, 1 cook's mate, 1 steward.

Rock Working Party.—(Europeans) 1 millwright, 1 shipwright, 2 masons. 1 smith, 1 miner, 5 seamen, 1 winchman; (natives) 7 boatmen, 2 wall-masons. 2 quarrymen.

When the steamers were discharging stone, 2 seamen were on board as winchmen.

The light was exhibited on the 10th of March, 1873, and has since been continued with regularity every night, from sunset to sunrise. The illuminant adopted was Ceylon cocoa-nut oil, which is obtained at Galle, at a price of about 2*s.* 3*d.* per gallon. This

oil is found, by experiments made at the Trinity House, to be equal in illuminating power, when employed in a properly-constructed lamp, to the best colza oil. This important work has been executed in a tropical climate by a few Europeans, aided by natives, and under exceptional difficulties, without loss of life or of limb to any person employed. The total cost of the undertaking, including all incidental expenses, was £62,039, being £2,622 below the original estimate for the work.

The success which has attended the execution of this work has induced the Board of Trade to order the erection of a similar lighthouse on the Little Basses reef, in accordance with a special design and estimate furnished by the Engineer of the Trinity House. This work is of even greater difficulty than that at the Great Basses, the reef being 20 miles farther from Galle, and a-wash only at low water. The Corporation of the Trinity House have undertaken the execution of this work also, and the Author is now employed in carrying it out, the vessels and plant from the works at Great Basses having been transferred and charged for that purpose.

The Author desires to record his sincere thanks for the kind assistance rendered by Sir Hercules Robinson, the late Governor of Ceylon, and to the Colonial officers, as well as to the Peninsular and Oriental Company, and their officers at Galle and Bombay.

As incidental to the history of the Great Basses lighthouse, it may be added that the chief portions of the 'Gordon' cast-iron tower, inclusive of the lantern and illuminating apparatus, are being utilised, from designs furnished by the Engineer of the Trinity House, in the construction of a lighthouse on the Bird Rock, Bahamas.

The Paper is illustrated by a series of drawings and diagrams, from which Plates 19 to 23 have been compiled.

[Mr. Harrison,

Mr. Harrison, President, said he was sure it would be the wish of the Meeting to accord to Mr. Douglass their thanks for his exceedingly interesting and valuable paper. Mr. Douglass's brother was present, and would no doubt reply to any questions that might be put, or observations made.

Mr. Michael Beazeley congratulated the Author on the ability displayed in carrying out a work attended by no slight difficulties, and on the success which had been attained. He had been for some years intimately connected with Mr. William Douglass in works of a similar character, and he was certain that whatever difficulties might have to be encountered, and they would be extremely formidable, in the erection of the Little Basses lighthouse, Mr. Douglass's courage and ability would enable him to grapple as successfully with them as with those met with on the Great Basses. He had been particularly struck by the small number of European hands employed on such a work. The total rock party of Europeans was only twelve, and the number on board the three vessels employed eighteen, making a total European party, excluding the engineer, of thirty. That was a very small force to accomplish such a work, including as it did only five skilled mechanics, because the difficulties in carrying it on were much greater in a tropical country than in a similar work at home. Here if anything was wanted it could be easily obtained; but no such facilities existed in a case like that of the Great Basses. The expense incurred, however, appeared to have been rather heavy, amounting to £62,039. The tower contained 37,365 cubic feet. The solid base, which contained 25,077 cubic feet, was there previously, and had no doubt been paid for. If that base had not existed its cost would have had to be added, and taking the contract price of 7*s.* 3*d.* per cubic foot delivered at Galle, the 25,077 cubic feet would have called for an outlay of £9,090, bringing the total up to £71,129, and that would come out at £1 18*s.* 1*d.* per cubic foot. He considered that rather high, because the Wolf Rock lighthouse, which was an exceptionally expensive one, cost only £1 8*s.* 2¼*d.* per cubic foot. He could not gather from the Paper if the cost of the vessels was charged to the work. If it were included, of course the high price would be at once accounted for. Towards the end of the Paper, however, where the Little Basses was spoken of, it was stated that the vessels and plant had been transferred and charged for that purpose. He wished to know if the ten stones per hour which were discharged was the maximum or the average. He had no note of the rate at the Wolf Rock, but at the Longships, where

barges were used, five and a half stones per hour was the average. The barge was moored very close in, within 8 or 10 feet of the landing place in fine weather, yet the rate was only five and a half stones per hour. He therefore thought ten stones must mean the maximum at the Great Basses. The average number of hours worked on the rock was eight per day, which for one hundred and ninety-four landings would give fifteen hundred and fifty-two hours. Each steamer carried 120 tons of stone; each stone weighed $2\frac{1}{2}$ tons; giving fifty stones per steamer, or 1,620 cubic feet. The 37,365 cubic feet in the tower were landed and set in eleven hundred hours, which would give 34 cubic feet of stone set per hour during the working season, from the laying of the first to the last stone. Now the 1,620 cubic feet, or fifty stones, in the steamer, at ten per hour, could be discharged in five hours. The fifty stones would require forty-eight hours in setting, or six days of eight hours each, so that the steamer could discharge her cargo, return to Galle, load and return again before the stones were set, and as there were two steamers employed, of course the work was conveniently done. He thought, however, that ten per hour would be found to be too high an average. Long trials had so perfected the knowledge of the proper construction of these towers, that it was difficult to suggest any improvement; but he thought it would be an advantage to diminish the number of windows in the service room. The vibration caused by the lantern during high winds was considerable, and as the rooms were increased in diameter the floor stones had a greater tendency to tip, and it was advisable to get as great a weight on them as possible to hold them down. If the number of windows in the service room were reduced from four to three it would, he thought, be an improvement. In a small way he had himself suffered from the Great Basses not being illuminated. When he was returning from Calcutta, although the east coast of Ceylon was kept in sight all the evening, the captain was so afraid of the Great Basses Rock, that directly it got dusk he kept the course of the vessel to the south-west, till at dawn of day they found themselves 60 miles to the south-west of Galle, quite out of sight of land. Comparisons were certainly invidious, and he might be supposed to be prejudiced in favour of the corporation with which he had been for so many years connected; but he could not help referring to the miserable failure which caused £40,000 to be spent in doing nothing whatever as compared with what was accomplished as soon as the work was handed over for execution to the Trinity House. When he was at Galle in 1859, he saw the stones lying on

the glacis of the fort, and made inquiries why they had not been placed in position. The only explanation he could get was that there was great difficulty in laying the foundation. That was self-evident, as not a single stone had been put in position, but every difficulty vanished before the courage and ability of Mr. Douglass when he undertook the work.

Mr. Redman referred to the cost of some lighthouse towers nearer home. The Bell Rock lighthouse, of nearly the same height (117 feet) as that on the Great Basses, cost £61,331; the Skerryvore lighthouse, with an altitude of 158 feet, cost £83,126. No portion of the literature of Civil Engineering had met with greater attention than that relating to the construction of lighthouses; but it would be admitted that this Paper, following as it did that by Mr. J. N. Douglass describing the construction of the Wolf Rock lighthouse,[1] was no mean addition to that literature, which ranged from the well-known folio of the great master of the art, Smeaton, to the works of Stevenson on the Skerryvore and the Bell Rock lighthouses, and to the numerous Papers in the records of the Institution. It was in many cases fallacious to compare the cost of such works, for the conditions were extremely various. He thought the Author had scarcely sufficiently described the geological structure of the rock, and the material used in the construction of the tower. He also wished to have some further and more detailed explanation of the bonding of the courses.

Admiral Collinson expressed his admiration at the arrangements which had been made for landing under great difficulties. As a sailor he considered the way in which the vessels were moored was a perfect specimen of what ought to be done where a difficult surf had to be dealt with. He also highly approved of the construction of the vessels. He went on board one before she left England, and was greatly delighted with its wonderful adaptability to the exigencies of the case. On behalf of the Trinity Corporation, he wished to express their sense of the great obligations they were under to Mr. Douglass for the successful issue of the undertaking.

Mr. Shearer said the granite used in the construction of the Great Basses lighthouse was supplied from his works at Dalbeattie, in Scotland. The mode of construction adopted by Mr. Douglass made the structure almost a solid mass of granite, which would in all probability be everlasting. It certainly would not be subject to any annual outlay for painting or repairs, as would have been the case if built of iron. The stones for such a structure could be

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxx., pp. 1–28.

despatched to any distance with the utmost regularity and safety. The first two or three cargoes were forwarded in sailing vessels, the rest in steamers *viâ* the Suez canal. The order for the working was put in hand on the 4th of January, 1870, and in October 1871 the last cargo was delivered at Galle. There were many advantages to be gained by using materials prepared in this country. Among others, the engineer, if resident in England, would have an opportunity of testing and examining them before they were sent away for distant foreign works. In this instance the tower was built in sections in the quarries under Mr. Douglass's inspection, and each block was marked for its particular place, so that little skill was necessary at the Great Basses in putting them together. Between nine hundred and one thousand blocks were used, and only one was damaged by accident at Galle; but as spare stones had been provided, capable of being worked into whatever shape was required, no inconvenience resulted from the accident.

Mr. J. N. Douglass, replying to Mr. Beazeley's questions, said ten was the average number of stones landed per hour, twelve the maximum. If the stones had not been landed with such rapidity, many opportunities would have been lost, as it sometimes happened that the steamers could not ride near the rock for more than two or three hours during one day. He did not agree in the opinion that the cost of this work was heavy. It was true the cost of the granite base of the 'Gordon' light house was not included in the estimate of £64,661, or in the actual cost of £62,039. The cost of this base delivered at Galle was about £9,526, which would give a total for the structure of £71,565. Now, in this was included two steamers and a light-vessel, less their actual value on the completion of the work, at which value they were transferred to the works at the Little Basses lighthouse. The actual charge to the work for the light-vessel, and her maintenance during the time the work was in hand (about £8,004), should fairly be deducted, thus reducing the cost of the work to £63,561. It was well known that wages and the cost of materials had greatly risen of late years; yet this work had been executed in a tropical climate, and at a distance of nearly 7,000 miles from this country, at a cost which would compare favourably with that of similar works at home. The Bell Rock lighthouse, of 28,530 cubic feet, cost £1 19*s.* per cubic foot; the Edystone, of 13,341 cubic feet, cost £2 19*s.* 11½*d.* per foot; and the Great Basses, of 47,808 cubic feet, cost £1 6*s.* 7¼*d.* per foot. No really fair comparison could, however, be drawn in the case

of such structures, because of the variety of circumstances, and the different conditions to be dealt with. But, on the whole, remembering that Smeaton's admirable work, executed under the personal superintendence of that able engineer, cost £2 19*s.* 11½*d.* per cubic foot, he did not think such a work as that now on the Great Basses, fitted with all the modern improvements in engineering and optical science, at £1 7*s.* per cubic foot, could be considered costly. The subject of the windows of the service-room had received careful consideration. The late Professor Faraday used to say that the lighthouse commenced at the floor of the service-room, and that the lantern should be ventilated from the service-room windows. As it frequently happened, in stormy weather, that only the lee window could be kept open, it followed that with four windows there was more certainty of a lee window, and consequently of proper ventilation of the lantern. Without proper ventilation condensation occurred on the internal surface of the glazing of the lantern, and the efficiency of the light was thus seriously impaired. The system of ventilation, as arranged by Professor Faraday, was as follows:—The air was admitted at the windows of the service-room (in which was a stove for heating in cold weather), ascended through a perforated grating surrounding the lantern-floor, over the internal surface of the glazing (thus preventing condensation) to the space between the roof and the ceiling, by an annular aperture surrounding the latter, whence it reached the cowl, the circulation being invigorated by the heat of the funnel of the large central lamp. He knew of no case where there had been any indications of weakness from the adoption of four ventilating windows in the service-room, therefore he preferred four to three. His brother had estimated, as a consequence of the erection of the Great Basses lighthouse, that the voyages of passing steamers had been so shortened that the saving in coal, irrespective of time and wages and interest on capital, had already exceeded the cost of the lighthouse. The tower, as stated in the Paper, was constructed of Dalbeattie granite, and the rock was a hard red sandstone. The granite base was from the Cornish quarries of Cheesewring and Penryn.

No. 1,319.—"On the Tracing and Construction of Roads in Mountainous Tropical Countries." By Major JAMES BROWNE, R.E., Assoc. Inst., C.E.

THE object of this Paper is to put on record facts noticed, and precautions found necessary, whilst making roads through countries of which the physical features, as compared with England, are on a very large scale. For instance, the Hindustan and Thibet road is nowhere less than 5,000 feet above the sea, and reaches 16,000 feet. The Kangra valley cart-road runs for more than 90 miles across the whole drainage of mountains averaging from 18,000 to 24,000 feet in height; the annual rainfall of the district varies from 180 inches to 220 inches, of which 170 inches have been known to fall in the two and a half months of the rainy season, and $5\frac{1}{2}$ inches in one hour. The statements herein contained refer to Indian practice, and will not necessarily hold good for Europe, or even for other tropical countries differently circumstanced as to climate or geological formation.

Mountain roads can be divided into two classes. The one crosses or is taken along the main or higher ranges, the other over the lower or subsidiary ranges. Both have their peculiar features; but it is believed that the latter class generally presents the most serious engineering difficulties. This may at first sight seem unlikely, until it is remembered that some of the highest Himalayan passes, like that over the Chang-chenmo, consist of undulating downs, and that the rain-clouds from the plains, breaking against the first main ranges, and discharging on the subsidiary hills, do not generally reach the inner lines of mountains, and are quite unknown on the high table lands of Thibet. Again, in the higher ranges, the soil, being mainly composed of hard rock, does not allow every little channel to cut for itself a deep and ever-increasing chasm, as in the comparatively soft soil of the lower ranges, and renders the bridging

an easier matter. The great rocky cliffs of the upper Himalaya, though far more imposing, are not more difficult to deal with than the rotten gravel and clay ravines of the Sewaliks and Salt Range; and are certainly far less dangerous cliff-climbing.

In the estimate here made of the relative engineering difficulty of road-making in the main and secondary ranges, cost is not included. The sub-Himalayan valleys, being amongst the richest and most thickly-peopled in India, can supply a fair amount of labour of all kinds; which has to be imported, at greatly increased cost, when works are carried out on the mountains above them.

The first thing to be remembered in the laying out and general planning of a mountain road is, that to no other kind of work is the motto "More hurry worse speed" more thoroughly applicable. No matter what amount of delay or labour may be entailed, the engineer should examine for himself every possible line; for no map of a really mountainous country, however admirably executed, can make up for personal knowledge. An old-established line of traffic should not be hastily abandoned for one that presents greater engineering facilities, and apparently equal commercial advantages. In a mountainous and thinly-peopled district local circumstances, which would never strike an engineer, are all-important to a native trader. For example, in one district of the Punjaub a new road has been made from the hills to the plains, which, it was thought, would at once draw away all traffic from the old, circuitous, and greatly more difficult line. Far from it, however. The old road is used, and the new one is not, for the simple reason that, whereas both lines are thickly wooded, the trees on the new line are acacias and thorn bushes, and those on the old provide excellent forage, for five days' march, to the traders' beasts of burden. These and similar cases are of constant occurrence; and as in canal, so also in road-making, the natives of India have generally good economical and local reasons for the selection of their old lines of traffic.

The next thing to determine is the number of possible lines between the extreme points, and the main obligatory points on each. These are, first, towns and villages; and secondly, saddles or passes, which fix the general gradient. The total sum of rise and of fall between the common extreme points on each different line has then to be found, for which purpose a good aneroid barometer will give sufficiently accurate results.

There are many other considerations of expense—bridging, value of land, &c.—which must have their due weight in the selection; but there is no broad principle so generally applicable as this:

"The best line for a mountain road is that on which the total sum of the ascents and of the descents between the extreme points is the least." This, though almost self-evident, is often disregarded without sufficient cause. Sometimes a deep river, chasm, or line of vertical cliff presents itself, and is regarded as an insuperable difficulty, it being forgotten that one great evil may be easier to overcome than a number of smaller ones. Nowhere is one so easily misled by appearances as on a mountain road; and the total sum of rise and of fall on any particular line affords an impartial and mechanical check upon the engineer's personal equation, to use an astronomical term, which should not be disregarded without valid reasons on other grounds.

At elevations exceeding 8,000 feet attention must be paid to the action of the snow in winter, as it is apt to be troublesome. The best approach, in an engineering point of view, to the station of Dalhousie lies through a ravine, which is, however, so sheltered from the sun, that the snowdrifts remain unmelted for weeks and bar the way; and it has been found necessary, in consequence, to take the new cart-road through otherwise very unfavourable ground. At Roksur, in Lahoul, a well traced road, but laid out in the height of summer, is impassable for the three spring months from incessant avalanches; one of which, $\frac{1}{2}$ mile in length, and exceeding 100 feet thick, carried off a stone bridge of 40-feet span, and remained unmelted for more than six months.

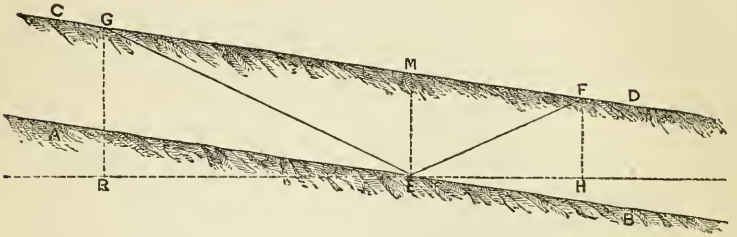
In finally laying out the work a few simple rules and precautions should be observed. In marking out the formation level, cuttings exceeding 10 feet or 15 feet in depth should as much as possible be avoided. In the stony soil of a hilly country no information is to be got by boring; and rock of the toughest and hardest description sometimes crops up where least expected. Where land, as in the mountains, is of little value, sufficient material for embankments is easily obtainable without having recourse to cuttings.

In the Himalayas, the northern slopes are thickly wooded, where the southern slopes are often quite bare. The wooded side should as a rule be selected, notwithstanding the increased labour of tracing through the brushwood, as the road will be more durable. The trees break the force of the rain as it falls, and the mould beneath them passes it off gently over the road, which, on the bare hillside, would be cut away by the unchecked rush of water.

Where the road-trace crosses a deep chasm formed by a river, the approaches should always be laid down stream, so as to get the

benefit of the slope of the river bed. This is best illustrated by Fig. 1.

Fig. 1.



Let A B represent the sloping longitudinal section of the river bed; E the road crossing; C D the river bank, parallel to the river bed at a vertical height E M above it; R H a horizontal line. From E draw E F and E G, making equal angles with R H. It is then sufficiently evident that the down-stream trace, the gradients being the same, gets clear of the bank in the distance E F, and with the rise F H; whereas the up-stream trace requires the distance E G, and the rise G R—the difference being entirely due to the fall in the river bed. This is so clear as to seem scarcely worthy of notice; but it is, nevertheless, often neglected in practice, where the slope of the river bed, seldom noticeable except in long straight reaches, is apt to be overlooked.

A much discussed and disputed point in the trace of mountain roads is the use of zigzags. Their general adoption is not to be recommended; but, on the other hand, much has been said against them which is open to modification. They are, in the first place, said to entail incessant repairs. This is quite true, if the zigzag is used in a wrong place—where the side slope is steep, the soil rotten, and the drainage such as to cross the road several times. But if used in a right place, where the drainage of each reach of zigzag can, at the turning points, be thrown off clear of the road below it, and where the side slope is gentle and the soil firm, the amount of repair is little, if at all, greater than in the same length of straight tracing. Again, where the reaches are short, and the turning places consequently cramped, zigzags should not be tolerated; but where each reach is not less than 600 or 700 yards in length, and where a semicircular turn of not less than 50-feet radius can be obtained, the inconvenience is small, and the danger a minimum, especially with slow-going cart traffic. Heavy expense and difficult drainage are often avoided by the use of zigzags, which, notwithstanding the prejudice against them, seem perfectly legitimate when adopted for sufficient reasons and in suitable

localities. Paved short cuts should be provided at all zigzags, for flocks of sheep and goats, which will otherwise do more damage than any wheeled traffic.

The original trace must be a good deal easier than the gradient intended for the completed road. The allowance to be made varies with the nature of the ground; but in a general way

1 in 47 works down to 1 in 45,
1 in 37 „ „ to 1 in 35,
1 in 28 „ „ to 1 in 26,
1 in 22 „ „ to 1 in 20,
1 in 19 „ „ to 1 in 18,

or 5·55 in 100, which is usually considered the steepest admissible gradient for an unmetalled mountain cart-road in India. Where the trace rises steadily, the gradient must be broken at every 500 or 600 yards by 100 feet or less of slight counterslope, not merely to ease the cattle, but to break the drainage, which, on the cross drains happening to choke, causes great damage to one continuous slope.

In tracing a Himalayan cart-road, the fact should never be lost sight of, that length is the one thing sought for, to overcome the immense heights met with. Every possible foot of rise should be gained and never again lost.

As to instruments for tracing gradients along hillsides, for accuracy and rapidity combined, no clinometer or quadrant hitherto brought forward can equal an ordinary dumpy level, provided with telescopic legs for use in difficult ground. A properly collimated floating telescope, finding its own level without adjustments, would be a great boon to all engineers.

Having noticed these points in the tracing and original selection of a line, it will be well to pass on to the actual construction. The bridging is too large a subject to be entered into here; and the remaining works can be classed under the following heads:

Excavation of Earthwork.
Retaining Walls.
Surface Drainage.

No attempt should be made, in the first season, to complete a road with neatly-dressed slopes and finished surface drains. In the Himalayas no earthwork takes its bearings, or becomes permanent, under two rainy seasons. Landslips occur with every shower and every hard frost, till they have worked them-

selves out. On the Dalhousie cart-road, the mere cutting out of the hillside to 14 feet in width determined a landslip upwards of 800 feet back from the edge of the road, and parallel to it for about 700 feet. Drainage cuts and retaining walls were made to secure the road, but all to no purpose. The landslip was at last left to itself, a party of workmen being merely told off every morning to help the rubbish over the road; and in the three rainy months the whole mass of earth, rock, and trees worked itself off, leaving a solid substratum of soil, and giving no further trouble. During the heavy rains from June to September 1871 a forest of deodars of several acres disappeared in one night, slipping down into the river Beas at the foot of the mountain. Under such circumstances it is useless to lay down in specifications certain angles of slope for different soils; and it is true economy to allow the rains to remove every shaky landslip and rotten bit before any kind of dressing of slopes and surface is attempted. It is discouraging to see the work of months buried in a few days, but it is a trial which an engineer must submit to before he can complete a Himalayan cart-road.

The whole proposed width of completed road should be cut out of the solid hillside. A few feet of extra width is readily and cheaply obtained from the made earth of the side cutting; but it is false economy, quickly found out in the first week of the rainy season. This does not, however, apply to a rocky hillside, with a gentle side slope, where, with a little rough building, half of the road may be carried on the rocks blasted out of the other half. The sides of cuttings and embankments having once taken their natural bearings are generally protected by turfing. Where, as is often the case, sods are not procurable, a successful method is to cover the slopes with a layer of about 3 inches of mud plaster, composed of earth, sand, and cow-dung, and then sow broadcast with American grass seed, which as a rule grows better in India than that obtained from England. In some districts boulder and slate pitching takes the place of turfing.

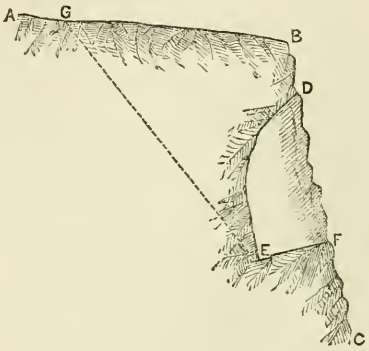
The vertical lines of cliffs unavoidably met with on the best traced lines present the most formidable obstacles. There are three different methods of forming a road along their face. The most expeditious is to establish a gallery, carrying the road on cantilevers of iron or timber. This plan, however, is only suited for mule or bullock roads, and is inapplicable for cart roads. It was originally largely employed on the Hindustan and Thibet road, but has since been replaced by half tunnels blasted out of the rock. As

these galleries are quickly constructed, and are useful in opening out temporary communications, it may briefly be explained how they are commenced. From the nearest possible standing point a gangway of lashed scaffolding poles is run out horizontally along the face of the cliff, the near end being held down by two leaded jumpers, or by lewises let into the rock. A workman adventures himself to the farther end, and drives into the rock a jumper-hole, slanting about 45°, which, when sufficiently deep, receives an iron bar run with lead. To this support scaffolding is lashed, which acts as a new starting-point from which to advance another step. When the scaffolding so supported has extended along the whole length of the cliff, arrangements can be made for fixing the permanent cradles and cross-beams to carry the gallery. Where the cliff is not too long, time is saved by stretching a slight rope-bridge along the face, which affords good footing to a native cliff-climber, who prides himself upon venturing unassisted, wherever the rock is sufficiently rough to give a grip to the tips of his fingers and toes. Where, as on the Rogi cliffs, the vertical drop exceeds 1,400 feet, with about 4,000 feet of precipice beyond it, this driving of the first jumper-holes is nervous work. It is noteworthy that on the Hindustan and Thibet road all the most dangerous climbing was done by a Thibetan, who lived entirely on alms, refusing all pecuniary remuneration for what he considered a religious duty. The galleries were 7½ feet wide, the supporting cradles being from 12 feet to 15 feet apart.

The other modes of forming a road along a cliff are, either by blasting in the usual manner, or by the use of mining galleries and large charges of powder. Blasting is a slow and tedious operation, and its prime cost is heavy; but once done, the work may be trusted to give comparatively no further trouble. The small charges bring down just what is required, leaving the rock sound and free from shakes. Great mines do the work far cheaper, far quicker, and almost at a blow; but no care or experience can prevent the cliff being occasionally so shaken as to cause incessant slips, continuing sometimes for years, and the road so easily formed comes, in the long run, to be rather expensive. The engineer must, however, determine, in each particular case, where he must blast, and where mine. For example, in Fig. 2, if A B C be the section of the cliff, and the rock be sufficiently hard and stiff, he can blast out a half tunnel like D E F; but if it be too soft and rotten to admit of this, the best plan, if B F be any great height, is to blow out the whole piece G E F by a large mine

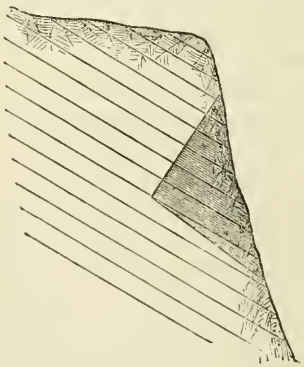
at E. Mining should not, as a rule, be employed where there is any chance of the powder acting in the direction of the dip of

Fig. 2.



the strata, as the result is to blow out a piece, as shown by the shaded portion (Fig. 3), which, before it can be rectified, entails

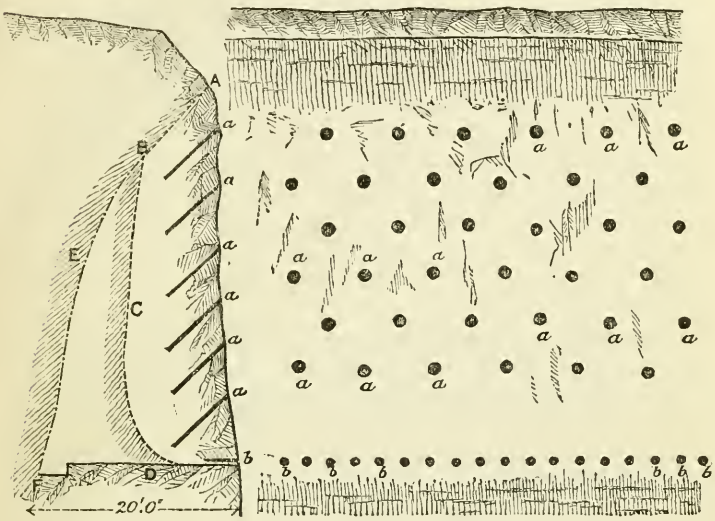
Fig. 3.



much labour and expense. There are cases, however, where the half tunnel could not be used, and where the brow of the cliff is so high above the proposed road-level that the cost of blasting out the whole piece is prohibitive. Here there is no help for it, whatever be the lie of the strata, but to try the effect of heavy mines.

The general mode of attacking a vertical cliff, and of forming a half tunnel, is shown in Fig. 4. The large blasts, *a*, *a*, *a*, driven

FIG. 4.



8 feet in depth, at an angle of 45°, are 7 feet 3 inches apart horizontally and 5 feet vertically, disposed checkerwise. The small holes, *b*, *b*, *b*, 3 feet apart and 3 feet deep, are not fired, but merely serve to determine and facilitate rupture at the proper level. These blasts when fired, as far as possible simultaneously, generally blow out or loosen a piece like A B C D. The remaining space, B E F, is dealt with in the same manner. Nitro-glycerine, being merely tamped by pouring water into the blast holes, has a great advantage over gunpowder as an explosive in such inaccessible situations; but its tendency to freeze renders its use dangerous at great altitudes.

Where kunkur rock is met with, special cartridges are employed for blasting. This substance, a kind of limestone conglomerate, is best described as exactly resembling petrified sponge, which, whilst allowing the powder to blow out through its pores, is so hard and tough as to defy the best steeled picks and jumpers. These cartridges were originally made of cast iron; but afterwards of four thicknesses of the stoutest tin plate solidly put together, a small hole being left in the top to receive the priming needle. When loaded with fine grained powder they gave the most ex-

cellent effect, confining the explosive gases, and tearing off huge blocks of the kunkur.

On one section of the Hindustan and Thibet road, adjoining the glaciers, and where wood fuel was abundant, the use of blasting was abandoned for over a year in favour of wood furnaces. The rock, when intensely heated, and then quickly deluged with snow water, was found to break up and crack, with a great saving of time and labour. This plan has, however, since been abandoned, the fuel having been almost exhausted.

The chief difficulty in dealing with native quarrymen, who are otherwise generally well up to their work, is to prevent their wasting time and powder in sinking shallow blast holes. The ordinary daily task of boring per man is about 60 inches in sandstone or conglomerate, 45 inches in limestone, and from 30 inches to 32 inches in granite.

In attacking a cliff with large mines, a line of scaffolding was first erected along the whole face, and tunnels were driven into the rock, chambers being formed at the ends of return galleries to the right and left. The charges were placed at a horizontal distance from the cliff face of 2 feet more than the proposed width of the road, and generally blew out the rock on both sides to a distance equal to their line of least resistance. The best charges, in feet and pounds, were after many trials found to be:

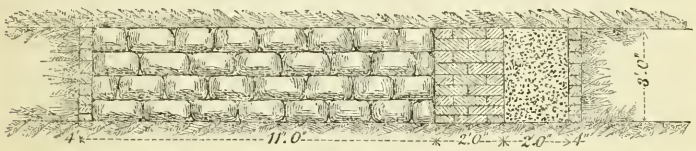
For granite or gneiss	$\frac{\text{L. L. R.}^3}{8}$
For limestone or hard sandstone . .	$\frac{\text{L. L. R.}^3}{10}$
For conglomerate or slate shale . .	$\frac{\text{L. L. R.}^3}{12}$

For instance, to form a road 20 feet wide, a gallery was driven 22 feet into the rock; then two returns of 22 feet each on either side. A charge of $\frac{22^3}{10}$, or 1,065 lbs. of powder being lodged in each chamber, blew out a length of cliff of 88 feet by 22 feet in width. The galleries, which were 3 feet high by 2 feet 6 inches wide, could, in conglomerate rock, be driven at an average rate of 1 inch an hour, and at a cost of about 2*s*. per lineal foot. The rate of progress was three times and five times less in limestone and in granite than in sandstone rock or conglomerate, which rendered mining a tedious operation. The galleries, for the most part, were chiselled with cold steel and not blasted out.

The quickest, cheapest, and most effectual mode of tamping

mines in such impracticable localities was by using sandbags made of date or palm-tree matting, and containing about ½ cubic foot of damp clay. With these, and a few half bags and quarter bags, the tamping was built up by native masons like an ordinary wall. At every 10 feet or 15 feet, according to the length of the mine, the galleries and returns were cut off by scantlings, 4 inches by 4 inches dropped into grooves cut in the rock. When the sandbag tamping had reached to within 4 feet of one of these doors, a wall 2 feet thick of ordinary sundried brick in mud mortar was built up vertically. The baulks being then slipped into the grooves, the intermediate 2 feet space was completely filled from above with fine dry sifted sand. The arrangement is shown in

Fig. 5.



Cushions of sand greatly increased the effect of the explosion. This systematic method of tamping could be done at the rate of 12 lineal feet an hour, or three times the rate of tamping with earth, in the usual and far less effective manner. The majority of the matting bags were, after an explosion, uninjured, and available for further use.

It has been found that great mines fired successively give much trouble in subsequent clearing, and occasionally explode uselessly through unnoticed fissures produced by previous explosions. Complete sets of mines were therefore generally fired simultaneously; nor was this attended in practice with any difficulty. At the Triloknath junction, on the Kangra valley road, two charges, each of 8,000 lbs., and fourteen charges, each of 1,600 lbs., altogether nearly 18 tons of gunpowder, were fired simultaneously with ordinary hose and Bickford's fuze, without any perceptible difference in the time of explosion. The effect was to bring down a cliff about 1,200 feet in length, and averaging from 300 feet to 400 feet in height. Each pound of powder dislodged about 200 cubic feet of conglomerate rock. The road was there formed at a cost for excavation of 7*s.* for 1,000 cubic-feet, which, if done by ordinary blasting, would have cost between 24*s.* and 28*s.* In limestone cliffs, each pound of powder could be expected to blow out about 115 cubic feet; in granite, not more than 75 to 85 cubic feet.

In blasting, but more especially in mining operations, it is often expedient to adopt some rapid but safe means of clearing off the huge masses of loose rock and earth, which, after an explosion, are too dangerous for men to work on, and too heavy to be dislodged. A few loaded 24-pounder howitzer shells placed under or behind these loose masses, and fired with a fuze, will seldom fail to bring them down, and to allow the work of clearing off to be safely commenced, which would otherwise be greatly delayed.

Dry masonry retaining walls are largely employed on most Himalayan roads, many of them being of great dimensions and of some constructive difficulty. As an instance may be quoted the wing-walls of a bridge, 350 feet in length, 70 feet in height, and built of split granite boulders, laid perfectly dry. The walls are on a curve of 50 feet radius, and are brought up on a batter of 1 in $4\frac{1}{2}$, with all the neatness of a brick wall. In the Western Himalayas the builders of these walls form a large hereditary caste, and it is remarkable to observe how, from long practice, but with the rudest implements, they will handle and accurately place unhewn stones weighing 4 or 5 tons at great heights, and in the most dangerous localities.

The use of sandstone is a frequent cause of failure in retaining walls, and, notwithstanding its clean splitting and good bedding, it is by no means so desirable a material for such work as granite or limestone boulders. The difficulty is to obtain sandstone which, however hard and durable it may seem at first sight, will not disintegrate under the tropical rains in damp situations, as in foundations below the level of the ground, and not exposed to the air. Retaining walls of what seemed most compact sandstone have suddenly collapsed, the underground courses having dissolved into sand. It is therefore usual to construct such walls, from the foundations to 2 feet above the ground line, with granite boulders, the rest of the wall being built of sandstone, which should, however, be as seldom as possible employed.

Next to the quality of the stone, the chief thing to be attended to in a dry retaining wall is to prevent the workmen giving fair outer facings of large stones, and filling them in with irregular chips. The proper specification for such a wall should be: "Each horizontal layer to be laid in regular courses throughout the wall from the outer to the inner face."

Many engineers employ timber framing at every 5 feet or 6 feet in height of the retaining walls. The stability is, no doubt, most materially increased; but, in such a rainy and intensely damp climate,

the wooden framing introduces into the wall an element of decay, and its use, although general, cannot be recommended.

Where expensive masonry in mortar is used, great economy will result from the best possible shape and dimensions being given to retaining walls; but where cheap dry masonry is employed, two simple rules will suffice for all practical purposes. The first, and probably the more important one is, never to use earth of any kind for the backing of a wall, but to fill in the space entirely with boulders or stone chips. This is sometimes rather expensive, but it has been amply proved by endless failures that, with such rainfalls, no care in ramming or previous wetting will ever save a dry masonry revetment from being blown up by an earthen backing. The second rule, which has been found to work well in very rainy districts like Kangra, is to make all retaining walls, whatever their height, 2 feet 3 inches thick at the top, with a batter of 1 in 4 on the outside, and 1 in 8 on the inside. In less rainy districts, a width of 2 feet 3 inches at the top, vertical at back, with a batter of 1 in $4\frac{1}{2}$ to the front, has been found sufficient.

Great attention is required to secure good foundations for retaining walls; and rock or hard clay should be chiselled or blasted out into steps, vertical to the proposed front slope of the wall. Its foot should be protected by boulder pitching, extending outward from 5 feet to 20 feet; the water from cross drains being thrown well clear, by means of wooden troughs or stone slabbing.

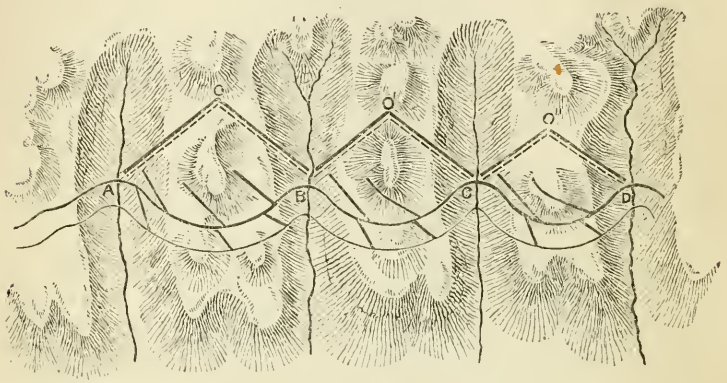
Revetment walls of masonry in mortar are seldom used, except when carrying the road along the edge of a hill torrent, and under a vertical cliff. This mode of construction is, however, more costly and less durable than blasting out of the solid rock. Dry walling, with masonry counterforts to break the force of the stream, has been used in such localities, but with no great success.

The mere excavation of a wide road along a hillside at once alters the whole system of natural drainage. It is useless to commence any drainage works until the annual rains have marked out the line of discharge across the great catchwater formed by the road. This naturally entails some damage; but many an expensive culvert has been built in a wrong place, which would have been saved at the cost of a chain or two of cheap earthwork. Drains or bridges can then be confidently built at those points (marked A B C D in Fig. 6) which, together with the great V-shaped drains A O, O B, O′ B, O′ C, &c., complete the main drainage system of the road.

The secondary drainage system, carrying off the rainfall within the V catchwaters, and on the road surface, consists of the side

drain along the road, the drains across and under it, and the smaller catchwaters above it.

Fig. 6.



The dimensions of the main V drains A O, O B, O′ B, O′ C, &c., naturally vary considerably. On some parts of the Lahore and Peshawur road they are 25 feet wide by 5 feet deep. On the Kangra road they average 10 feet wide by 3 feet deep; and it may generally be laid down that they should never be less than 6 feet wide by 2½ feet deep. Where the side slope is great, their floors and sides are protected by rough slate slabbing, boulder paving, or fascine revetments. In crossing the great moraines, or landslips of loose shale, the road can only be secured by double lines of such V drains, revetted with three rows of crossed and pegged fascines. These rapidly get clogged with clay silt, and form an impervious yet slightly flexible channel to carry off the drainage, which would otherwise cut away the shale like loose sand. Whilst on this subject, it may be noted that fascine foundations, on the Chat Moss system, are much used to carry the road across the great peat bogs met with in the lower valleys.

There can be no greater mistake than, for reasons of economy, to construct small drains of any kind for mountain roads in tropical climates, as they are certain to choke up on the first shower. The smallest secondary drain should not be less than 2 feet by 1 foot 3 inches; no cross drain, if provided with a movable slab top, being less than 2 feet by 2½ feet, or, if permanently covered in, less than 2 feet 3 inches by 2 feet 9 inches. To insure proper scouring, and an easy change of direction for the water, the cross drains have a floor slope of 1 in 12, and are built at an angle of 135° with the side drain, their ends being properly secured by boulder pitching.

The number of cross drains varies from 1 in every 120 feet in very rainy districts like Kangra, to 1 in every 300 feet in drier localities. Where the cross drainage is heavy, it is necessary to adopt saucer drains of coarse rammed concrete, 18 inches thick, supported by a retaining wall, and from 10 feet to 16 feet wide, with a depth of from 1 foot to 1 foot 6 inches. In the dry season this depression is filled in flush with the rest of the road. In the rains the earth gets washed away, and the concrete saucer does duty as a drain, presenting no obstacle beyond a jolt to a passing cart.

The main drainage is carried across the road through culverts, but more especially through large outlets in dry masonry retaining walls, covered in by stone slabs of from 2½ feet to 3 feet span. The requisite waterway is obtained by having several of these outlets, as also by the increased heights of the sides. For larger spans, up to 10 feet, and where slate is procurable, a dry rubble stone arch, built of picked stones neatly radiated and wedged up, is, whilst much cheaper, quite as strong and reliable as arching in mortar. Where building stone is scarce, concrete arches on dry masonry abutments are largely employed, the whole mass forming a monolith, rammed up in 4-inch horizontal layers. The usual composition of this concrete is—1 by measure of lime, 1 of sand, 1 of pounded brick, and 4½ of broken stone. With mortar masonry, or live rock, abutments, large spans are covered in by such concrete arches. The Durroon Bridge, on the Kangra road, is 48 feet span in the clear by 20 feet wide. The arch is entirely composed of rammed mortar, consisting of 1 part of boulder lime, 1 part of pounded brick, 1 part of sand (largest grain the size of a pea), no broken stone whatever being used. A specimen of this mortar, carefully tried in a testing machine, was found to crush under a power of 4,032 lbs., say 1·8 ton per square inch, Portland cement yielding under 0·45 ton. Besides being cheaply and quickly constructed, such a bridge has the great advantage in remote localities of requiring no skilled labour except for the centring. In this operation arrangements for striking can be dispensed with, as the concrete arch when setting expands, and lifts itself off the lagging.

The necessary waterway for large culverts depends very much on the nature of the foundations, and is probably more a matter of experience and observation than of calculation. As to the amount of rainfall over the catchment basin, there are many opinions; but the practice in the Kangra district has been to provide for 5 inches an hour over areas not exceeding 1 square mile; and this allowance, although sufficient, has not proved excessive.

Drainage should never be estimated by the floods, however severe, occurring during the first month of the rainy season. In tropical climates the three months of dry, hot weather preceding the rains so parch up the earth that the first floods of the season, however steep the hillside, are no criterion of what will happen when the soil has become thoroughly sodden, and cannot absorb additional moisture.

Marks shown by natives, as giving the maximum flood rise of a hill torrent, should not necessarily be distrusted because they differ in level on the two banks. With great falls in the bed, and consequent high velocity, the flood-water will swirl up from 3 feet to 5 feet higher on one bank than on the other. In the absence of other information, much may be learnt by searching for the dry chips and grass which, floating on the surface of the water, stick to the bushes and banks, and define the flood-rise long after other marks have disappeared.

Where the road skirts the foot of a great mountain-range, very peculiar conditions of drainage are met with. The fall in the bed of the mountain torrents diminishes suddenly from perhaps 200 feet in one mile to 30 feet in the next. The consequence is that vast quantities of silt are brought down and deposited in the lower reaches, where the beds of the torrents are constantly, though gradually, being raised, until the watercourses run along ridges considerably above the general level of the country. In ordinary floods the ground below and between these watercourses has merely got to carry off its own drainage; but in heavy rains the detritus brought down by the torrents chokes them up as the velocity diminishes. The pent-up waters of two neighbouring streams, topping the lip of the ridges that carry them, then spread over into the lower ground between them, which at other times is perhaps almost dry. The best plan in such cases is to build culverts or bridges on the ridges, and on the lower ground to have metalled gaps, sufficiently wide to allow the floods to cross them at a low velocity and at a fordable depth for carts, say from 1 foot 6 inches to 2 feet. It is also advisable to cut down the lip of the ridge, to within 1 foot or 2 feet of the ordinary flood-level to facilitate extraordinary overflows, and to let them move gradually on to the metalled gaps, which would otherwise be destroyed by the rush of water. These are generally protected on the upper and lower sides by masonry drop-walls, sheet piling, or, in sandy soil, a line of circular brickwork wells. The interior space is filled with boulders, coarse gravel concrete about 2 feet thick, or, where nothing else is procurable, brushwood fascines, pegged together

and covered with a layer of good metalling. The only means of preserving the gap from cutting up being to take the water over it in one smooth, unbroken sheet, the ground above and below it, for 300 feet or 400 feet, is cut down into a gentle uniform slope, paved with boulder pitching, the ends of the gap being further protected by great pear-shaped earthen groins, secured with sheet and fender piles. Some gaps on the Lahore and Peshawur road are over 2,000 feet in length, but are not found objectionable in practice.

To conclude the subject of surface drainage, it may be remarked that, whereas in Europe it may be controlled and even coerced over large catchment basins, it must in the Tropics either be entirely humoured or managed by subdivision into small areas.

The shape generally given to the metalled road-surface in cutting along a mountain side is a slope of 1 in 18 from the outside to the inside. It has been objected to this slope that it converts the road into a drain, which is cut away and becomes impassable in heavy downpours; and in some of the Madras hill roads the slope runs from the inside to the outside. Both systems have their respective advantages; but, on the whole, the inside slope is preferable when the cross drains are sufficiently large and numerous, and the side-drains rocky or properly protected by boulder paving. The usual practice is to adopt the outside slope until the drains are all built and the side-slopes have taken their bearings, when, as a permanent arrangement, the road is finished and metalled with an inside slope.

The metalling, which is generally cheap and good, consists of a 9-inch layer of broken granite, kunkur rock, or coarse slate shingle, and does not materially differ from an ordinary macadamised surface.

The usual width of a mountain cart-road varies from 18 feet in open ground to 12 feet along cliffs or in very difficult places; the maximum gradients varying from 1 in 18 to 1 in 25. The cost is very uncertain, and in no other kind of work is it more unsafe to estimate for one case from the known data of another. As an illustration, however, the following are the estimated costs of some of the lines:—

Chukrata Road	£1,500 a mile
Bridging light; labour pretty abundant.	
Kangra Valley Road	£2,300 a mile.
Bridging very heavy; labour abundant.	
Dalhousie Road	£2,700 a mile.
Excavation very heavy; labour scarce.	

To each of which, perhaps, £300 a mile might be added for metalling.

The farther end of the Hindustan and Thibet road, which may be described as an unmetalled mule road, 7 feet in width, with gradients of 1 in 6 to 1 in 4, cost about £500 per mile.

A Himalayan cart-road, if only from its small local traffic, great prime cost, and incessant repairs, would never pay as a commercial speculation and apart from its vast political and military importance to the British Government. Wire tramways, worked by water power obtainable from the mountain torrents, is a step in the right direction, and will probably supersede other means of communication.

March 10, 1874.

THOMAS E. HARRISON, President,
in the Chair.

No. 1,385.—"Gun-Carriages and Mechanical Appliances for working Heavy Ordnance." By GEORGE WIGHTWICK RENDEL, M. Inst. C.E.[1]

A few years ago gun-carriages were of the simplest character, and, though well-adapted to their purpose, were scarcely worthy the attention of the Civil Engineer. But of late, owing to the increase in the size and power of ordnance since the introduction of armour, gun-carriages have gradually become elaborate machines, and the appliances for working the monster ordnance now in contemplation will tax all the resources of mechanical science. The subject is of the greatest importance. It deserves and claims discussion in an Institution whose members have the widest possible experience of engineering appliances, and such a discussion cannot fail to be attended with public advantage.

The common form of garrison and ship gun-carriage (Plate 24, Fig. 1) in use fifteen years ago is well known. It ran in and out upon small wheels or trucks having disproportionately large axles, designed to create friction for the absorption of recoil; or the rear trucks were dispensed with, and a block of wood, called the rear chock, was substituted for them, the recoil being further arrested by the slope of the platform, or by a rope breeching. Elevation was given to the gun by raising the breech with hand spikes, and propping it with a loose quoin, or by a simple elevating screw under the breech. Training was effected by prising the carriage bodily sideways with levers, or by hauling it with tackles. The adoption of slides (Plate 24, Fig. 2), and traversing platforms for gun-carriages to run on, had been a great improvement; but levers and tackles, and, for ship use, breechings continued to form essential parts of the apparatus for working ordnance, and the carriages were most imperfect machines when great improvements in guns had been realised.

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[1] The discussion upon this Paper extended over portions of three evenings, but an abstract of the whole is given consecutively.

The first difficulty experienced in mounting wrought-iron rifled guns arose from the much greater violence of their recoil as compared with that of the old cast-iron guns; a disadvantage mainly resulting from their superiority in lightness, strength for strength. Serious objection was made to the new guns on this account. The service compressors first introduced with improved ordnance were found inadequate and unsuitable, and it became essential to devise an efficient break for arresting recoil. The conditions to be fulfilled in a mechanical break were:—First, to provide ample surface and pressure to give the requisite frictional resistance. Secondly, to cause the break to be self-acting, so as to remove the risk of accident. Thirdly, to make it capable of adjustment to meet the alterations in the force of recoil due to different charges and other changing conditions. Fourthly, to render it sufficiently elastic to meet variations of gauge of the rubbing surfaces. And, finally, to add as few parts as possible to the carriage, and those compact, strong, and accessible.

The first break or compressor, designed at Elswick to meet these requirements (Plate 24, Fig. 3), was tried in the year 1864, by the Ordnance Select Committee, on a 70-pounder timber carriage. In this compressor elasticity is obtained by a bow piece which spans the slide beam, and is capable of springing to any probable variation of the gauge of the beam, without sensible alteration of the pressure and consequent friction on the beam. Adjustment of the frictional resistance is provided for by the screw (A), which can be turned and set to any zero by means of the notched wheel (B) held by the catch (C). The compressor is rendered self-acting as follows: a lever (D) is attached to a quick pitched screw (E) passing through the bow piece opposite the adjusting screw, and runs at its outer end between stops or in a swivel-eye on the gun-carriage, so as to act on the screw whenever the carriage moves, but the rest of the compressor is disconnected with the carriage, and is free to the extent of the play it has between the transoms. It therefore does not move, when the motion of the carriage is reversed, until the transom behind reaches it and carries it forward, by which time the lever (D), having described a sufficient arc, has either clamped or freed the compressor, according as the motion is in or out. It will be obvious that, as the compressor is set up by the action of recoil itself, there can be no difficulty in employing any desired pressure on the rubbing surfaces, and that, as the pressure simply compresses the slide beams, it causes no distortion or straining of the slide structure. This compressor was afterwards adapted for iron carriages, by substituting iron boxes filled with wood for the friction-

plates (Plate 24, Fig. 4); and it has been extensively used for naval and land service with guns not exceeding 7 tons in weight.

The liability of timber to change of form and to rapid deterioration renders it a very unsuitable material for gun-carriages, and the great superiority of wrought iron, in unchangeability, durability, and strength, soon became apparent as gun-carriages were adapted to keep pace with the improvement in guns. A strong prejudice, however, long existed against the use of iron for gun-carriages, under the belief that shot would produce more numerous and dangerous splinters on striking an iron structure than on striking a timber one: but although this may be true of cast iron, it proved not to be so of wrought iron. In 1865 experiments were made at Shoeburyness, by firing against wrought-iron and timber carriages, and noting the effect on dummies set up to represent the guns' crew. Contrary to expectation, it was found that the splinters from the wood were more destructive than those from the iron gun-carriage, and the wooden carriage was disabled in a less number of rounds than the iron one. Similar experiments were subsequently made with field carriages of wood and iron, and with like results. It might be questioned whether one or two experiments could be considered conclusive of a question so much affected by chance; but it is evident that a timber carriage for one of the present heavy rifled guns, would be so cumbrous, and so full of iron-work in fittings and bolts, that it could not be struck by shot without forming numerous fragments of iron as well as of wood; and even were it superior to an iron carriage in this respect, its disadvantages in others would more than counterbalance that superiority. The use of iron is now thoroughly established, and a return to timber would be as impossible for heavy gun-carriages as it would be for the huge ships, which, through the adoption of iron-plate construction, are now built without difficulty.

In 1865 Sir W. G. Armstrong and Co. designed and constructed a 70-pounder wrought-iron naval carriage and slide (Plate 24, Fig. 5), in which they introduced an improved "compressor" made entirely of wrought iron. This carriage was tried in the same year on a gunboat at Spithead by Vice-Admiral Sir Cooper Key, whose approval of it, and whose advocacy of wrought iron as the material for future naval carriages, led to an order being at once given for a 12½-ton gun-carriage on the same system, subsequently tried and adopted by the Admiralty. The compressor (Plate 24, Figs. 6), in both these carriages, consists of a number of short plates on the carriage interlacing long plates or bars on the slide, in such a manner that when both are clamped together by the vice action

of the compressor jaws and the carriage is set in motion, the frictional resistance produced is that due to the pressure applied, multiplied by the number of sliding surfaces, *i.e.*, by twice the number of the fixed plates; so that the power of the compressor can be increased by merely adding plates without increasing the pressure applied through the vice jaws. The compressor is tightened by a quarter turn of the lever (A). The toe projects so as to catch a tripper (B), which turns it in the event of its being forgotten, and thus renders it self-acting. A second lever (C), fixed in any position on a notched arc, turns the screw nut (D) and adjusts the pressure applied, by altering the zero point from which compression commences. The rocking levers (F F) are sufficiently elastic to meet the slight variations of gauge to be expected in the bundle of bars throughout their length. The adoption of thin iron bars enables the friction to be so multiplied, by repetition of surface, that a moderate pressure suffices, and practically the compressor can be applied by hand with great power, with hardly an effort and in a moment. Perfect control is thus obtained over the motion of a gun on its slide in a sea-way, so that this compressor is superior to the one previously described, which only resists motion of the gun backwards or in the direction of recoil, and does not check its running out. The principle of increasing the frictional resistance due to any given pressure, by multiplying the sliding surfaces subject to that pressure, instead of increasing the pressure itself, was first applied to gun-carriage compressors in America. But although this important principle is common to both, the Elswick compressor differs from the American form in several essential particulars. As it is self-acting no accident can happen from its being forgotten. It is capable of easy adjustment, so as to regulate the recoil to any required extent under different conditions. It is applied instantly by a quarter turn of a lever, thus affording the means of perfectly controlling the motion of a gun on its slide in a sea-way. Finally, the adoption of thin iron bars in place of timber planks gives a great extension to the power of multiplying surfaces, and consequently of increasing the resistance of the compressor, while at the same time it renders it durable, and prevents the irregularity and uncertainty of action experienced with the American compressor. Contrary to general expectation, the iron rubbing surfaces have answered well, and are free from liability to seize, the amount of surface always being made ample. They want no attention, and may be allowed to rust freely. This compressor has been adopted almost universally for naval use, and to a large extent for land service also,

having been manufactured at Elswick for nearly every Power in the world.

Some of the leading types of carriages made at the Elswick Works will now be described. Plate 24, Fig. 7, represents a naval broadside wrought-iron carriage and slide for the 9-inch 12½-ton Armstrong gun. A section of the carriage is shown in Fig. 6. The cheeks are of double plates riveted on each side of a frame of iron. They are connected by a horizontal base plate and by vertical diaphragms, secured and stiffened by angle irons. The slide is formed of two rolled H beams, bent round and riveted together at the front, and braced by diagonal bars. This construction is simple, strong, and convenient, and has been followed generally in wrought-iron carriages. The self-acting plate compressor checks recoil, and controls the motion of the gun on the slide. An inclination forward is given to the slide, so that, as a rule, the gun will run out by itself into firing position whenever the compressor is eased; but it can also be run in or out when necessary by a pair of endless chains, set in motion by crank handles acting through toothed gear, or cupped wheels engaging the links of the chains. The chains pass through guides on the carriage, so formed as to seize them, when a hooked bar is dropped over an eccentric pin on the shaft by which the carriage is raised upon its wheels for running in or out. Thus the chains can be seized or not at will, in the act of throwing the carriage on its wheels, and yet run freely through the guides on recoil, or when not required for running in or out. The slide is trained about a front pivot, by a pinion gearing into a toothed arc secured on the deck, as first used by Captain Scott, R.N., the pinion being driven by the same crank handles as the chain gear, through a clutch worked by a foot lever. The training gear is locked by a notched wheel and pawl (Fig. 8), to prevent the gun breaking away under the influence of the motion of the ship. Another form of apparatus for running the gun in and out is the rope winch gear, introduced by Mr. Cunningham, of Gosport (Fig. 9). In this case the traction is effected by a rope laid over and biting in a groove of V section on a wheel driven by the winch. The same rope led round a conveyance-sheave to a ring-bolt in the deck serves to train the slide. This apparatus works well with guns of moderate weight, and has the merit of simplicity with the attendant advantage, so important in all war material, of small liability to derangement. Elevation is given to the guns by a pinion and toothed arc, and is easily effected, since the guns are now made without the breech preponderance formerly considered essential. The guns

are fixed at any elevation by a lever, which clamps the elevating pinion to the carriage cheek. Figs. 10 and 11 represent an 18-ton gun naval wrought-iron carriage and slide, of similar construction to that of the 12½-ton gun-carriage, but capable of revolving about a rear pivot as well as a front one, so that the gun may be shifted from one port to another adjoining, and be used in both. The racks and radius plates required on the deck for two corner ports of a battery under this arrangement are shown in Fig. 12. The special feature of the plan is the pivoting of a portion of the rack, by which means it is easily moved out of the track of the slide wheels during the shifting of the gun from one port to the other, and at the same time is available for training the gun in both ports. The pivoted rack is fixed in either position by a drop bolt, which, with the screw pivot, securely holds it in place. This renders unnecessary the turn-table used for the same purpose in several English ships. The slide or platform of a gun-carriage may be regarded as in itself a turn-table, and the addition of a second turn-table below is obviously undesirable. Such an addition is especially objectionable in a ship, for a large hole must be made in the deck, the deck beams must be cut and space occupied below, besides which a serious and costly complication in the structure of the vessel is introduced.

Figs. 13 and 14 represent a wrought-iron carriage and slide for land service, for a 15-ton gun. The two points of novelty, to which attention may be directed, are the method of training the platform, and the substitution for the usual tripping rollers under the carriage of a number of grooved rollers, permanently running on the slide, and sufficient to bear the shock of recoil. The training is effected by gear connecting the platform trucks, on the front and rear rails, in such a way as to drive them at a speed proportioned to the respective radii of the rails. The result is that the platform moves truly about the centre of both rail circles, and requires no actual pivot and pivot bars. The excessive difficulty often experienced in training heavy garrison carriages without actual pivots is due to the binding of the truck flanges against the sides of the rails, from a want of coincidence between the direction of the pressure applied to give the motion and of the resistance, causing the front or the rear to lag, and the platform to cease to move in a true circle. The coupling of a fore and aft wheel with proportionate gear removes this difficulty, and enables the platform to be trained with ease by the traction of the wheels alone, and without fixed fulcra such as the toothed arc required for naval service.

All British service gun-carriages are at present mounted on

their slides in such a manner as to recoil on a dead bearing, but to run out on wheels thrown into action by eccentrics or cranks. By placing the carriage permanently on wheels, and trusting more to the compressor to arrest recoil, the operation of "tripping" the carriage, *i.e.*, of throwing the wheels into action for running out, is avoided. In an earthwork or a barbette battery the men who do this are frequently much exposed; and in all cases "tripping" a heavy gun-carriage involves labour and time. By this alteration the gun may be worked more quickly, with fewer men, and in many cases with less exposure of the men. The power of the plate compressor is ample for the purpose of controlling the recoil and motion of the gun on its slide, at sea as well as on land, and the value of the natural friction between the carriage and slide, small in comparison with the artificial friction of the compressor, is dearly bought at the cost of an operation which occupies a large portion of the time and labour of working heavy ordnance, and involves other serious disadvantages.

The loading of heavy guns has not hitherto been facilitated by the introduction of mechanical aids to the same extent as the work to be done in running the gun in and out, and in elevating and training it to deliver its fire. Winches are used for hoisting the shot to the muzzle, with cranes or runners in some cases, and several forms of shot-bearers have been devised for different circumstances; but the ramming home of the shot, and the sponging of the bore, are still done by ramrods, which are rapidly attaining dimensions totally unmanageable. The ring shot-bearer (exhibited) was designed especially for use in turrets, where the shot has to be brought up vertically through small apertures. It carries the shot by locking itself on the front row of studs, and lifts it so that it may be turned to a horizontal position at the muzzle, and enter the bore of the gun with the studs opposite the grooves. The vice shot-bearer (also shown) is more adapted for deck use. It is intended to be hooked on to the muzzle of the gun, where it forms at once a shelf and guide corresponding in diameter and in the position of its grooves to those of the bore, so that the shot may be pushed at once into the bore. The vice jaws hold the shot so firmly, that the shot cannot slip off the bearer while being conveyed to the gun, until the handles are let go. A rope or canvas sling is, however, found to answer for naval broadside use, with the service form of projectile, and has the merit of lightness and simplicity.

The result of the adoption of these mechanical arrangements for the application of manual power to the working of ordnance, has

been that guns up to 25 tons weight are now worked with more ease, safety, and rapidity than guns of one-fifth that weight were formerly.

The size of ordnance continues, however, to increase by rapid strides. There are already many rifled guns in existence of 36 tons or 38 tons weight, throwing 700-lb. shot. Guns of nearly double that weight are actually being made, and there is no manufacturing obstacle to the construction of still larger artillery. It is difficult, indeed, to place a limit to the size of gun that can be produced on a system, like that of Sir Wm. Armstrong, under which it is built up of concentric cylinders superposed in layers, whose number may be increased so as to form an immense total thickness, without involving any one piece of unmanageable dimensions. The powder pressure attained with large charges would, possibly, first impose a limit on the size of guns; but recent experiments and investigations give ground for the belief, that even with charges vastly exceeding any yet used, the powder pressure may be regulated and kept within prescribed bounds. Hence, then, the adoption of some inanimate power, in the place of mere hand-labour, for loading and working heavy ordnance, desirable as it already is for existing guns, will become an absolute necessity for guns of the immediate future. Instead of complicating mechanism, the abandonment of manual labour will tend to simplify it, because the number of men employed cannot be much further increased; and the train of mechanism required to apply the constant and limited power of men, to the forces to be exerted in loading and working heavy guns, becomes larger and more complicated as the weight of the guns is increased.

Adopting the steam engine as the most ready and convenient source of power, it is believed that that power will be best applied through the medium of water under pressure. The simplicity and compactness of hydraulic machinery, the circumstance of its direct action rendering toothed gear unnecessary, and the perfect control it gives over the motion of heavy weights, especially adapt it for the purpose. Power sufficient for the heaviest gun may be transmitted by water through a very small pipe, for long distances and by intricate ways; so that a steam pumping engine may be placed in a fort or ship, in such a position as to be absolutely secure, and supply power, by this means, for working many guns.

The drawings and the working models illustrate some of the arrangements experimented with, or now in progress at, the Elswick Works, for loading and working guns by hydraulic machinery.

The cylinder or press (Plate 25, Fig. 15) performs the double

office of checking recoil and moving the gun in or out along the slide. The gun on recoil drives back the piston and is arrested by the resistance which the valve (D) offers to the escape of the water from the cylinder. The valve is loaded with a spring, which may be adjusted to give any required resistance, and so meet the variations of the force of recoil. It is also partly balanced, to lessen the load required upon it. The area of the piston-rod is one half that of the piston, and the gun is run out by admitting the water pressure to both sides at once. For running the gun in, the pressure is admitted to the front of the piston only, the exhaust being at the same time opened to the rear. Clack valves in connection with a waste-water tank are used to insure the cylinder being always full, and there is a relief valve on the front for preventing any excessive strain. On the rear the recoil valve acts as a relief valve upon occasion. It will happen in some cases that the pressure required on the valve (D) to arrest recoil falls short of that necessary for running the gun in or out, in which case the water admitted to the cylinder for the purpose would lift the valve and escape to waste. This is provided for by making the act of opening the cylinder-inlet valve (A) place an additional load on the recoil valve (D), retaining it there so long as the inlet valve remains open. Fig. 15 shows one method of placing the extra load on the recoil valve, viz., by a small inverted press having in its normal condition an open communication with the waste-water tank, which communication is closed, and the press charged with water under pressure, by the first movement of the lever employed to open the inlet valve (A) of the recoil cylinder.

Experiments, made at Elswick with a recoil press of the nature described, gave very satisfactory results. It was found that the recoil could be regulated with precision, and that the most perfect control could be exercised over the movement of the gun on its slide. The same arrangement of recoil press may be used independently of the application of hydraulic power, to check recoil and to control the movements of gun-carriages on their slides. The loaded valve not only serves to arrest recoil, but as a working valve to govern at will the passage of the water from one side of the piston to the other, and, by thus controlling the motion of the piston, to govern that of the carriage to which it is attached through the piston-rod. The press is therefore as available for sea service, where the motion of the ship makes perfect control essential, as for land service, and for carriages running permanently on wheels on inclined platforms as for those arranged to be tripped. The hydraulic, or, as it would more correctly be

called, the hydro-pneumatic buffer, introduced some years ago by General Clerk, R.A., late the Superintendent of the Royal Carriage Department, for existing garrison carriages, is not applicable in either of these two cases. Like the recoil press, already described, it consists of a cylinder fixed on the slide, and fitted with a piston attached to the carriage by a piston-rod. The piston is perforated with small holes, and when recoil takes place the water is compelled to pass through these holes from one side to the other, the friction thus caused arresting the recoil. The apertures being constant, while the velocity of recoil varies from 15 feet or 16 feet per second at the commencement to zero, the resistance varies excessively throughout the stroke, and the maximum strain, for which the strength of the parts must be calculated, is greatly above the mean. An air space is provided to lessen the violence of the first action, and to allow, by compression, for the displacement of the piston-rod entering the cylinder; but the buffer will not, of course, retain the carriage in any position on an inclined slide, nor will it restrain the movement of the carriage and gun within safe limits of speed under the influence of the motion of a ship; so that it cannot be used for sea service, except in conjunction with a frictional break of sufficient power to control the gun when being run out or in on its slide.

In the turret arrangement shown in Plate 25, Fig. 16, the carriage is placed upon permanent rollers, in view of the advantages of rapidity and ease of working already previously shown to result from dispensing with the operation of "tripping." In the same carriage the gun is made partially muzzle-pivoting, by hinging the slide at the rear horizontally, and raising and lowering the front end upon a press to three or more positions, in which it can be chocked by turning under it the bracketed supports. In 1867 and 1868 a partial muzzle-pivoting carriage was made at Elswick for an 18-ton gun, in accordance with the proposals of Colonel Inglis, R.E., who adopted the plan of raising and lowering the trunnion bearings of the gun in vertical grooves formed in the carriage. Captain Scott, R.N., has modified the arrangement, by the substitution of hydraulic jacks, in combination with chocks, for the screw-lifting gear used by Colonel Inglis, and by the application of the jacks to act from fixed positions in the slide or turret floor on a bow piece carrying the trunnions. In this form the system has been applied for heavy turret guns in the Royal navy. It makes the carriage, however, high and top-heavy, a disadvantage for naval service, which would become more serious with every increase in the weight of guns.

The object of "muzzle pivoting," or, more correctly, of "port pivoting," is the reduction of the size of the port. This object would be obtained sufficiently for most cases if the trunnions could be placed on the gun very close to the port, and the part of the gun which projects outside the port be lowered as the gun recoils. The arrangement shown in Fig. 17, and illustrated by the working model, is designed to effect this. At the same time, to enable exceptionally heavy guns to be carried with perfect security in a turret under any circumstances of weather and motion of the vessel, a carriage is dispensed with, and the gun is supported on three points, viz., on a pair of trunnions placed well forward, where the diameter of the gun is less than at the breech, and on a saddle under the breech itself. The trunnion arms rest in two sliding blocks, which run in guides on fixed beams, built on the floor of the turret. Immediately behind each block, in the direct line of recoil, are two hydraulic cylinders, for checking recoil and running the gun in or out. The cylinders are connected by a pipe, and have a common recoil valve, so that the two pistons must act in unison; and the guides on the breech of the gun running between the slide beams further insure the simultaneous movement of the pistons, by preventing any horizontal rotation of the gun with reference to the slide. The saddle which supports the breech slides along a beam or table beneath it. The front of the beam can be raised or lowered by an hydraulic press to give any desired elevation, but the rear is pivoted at a point corresponding to the horizontal position of the gun; consequently the gun returns always to the horizontal position as it recoils, whatever elevation it may be fired with, and clears the port in coming back. A curve is given to the beam or table to ease the shock which would come upon it when the gun is fired at elevation. A lifting press under the rear of the elevating table is required to depress the gun to the loading position in the arrangement described, but it is not an essential part of the system, and is dispensed with in the loading arrangement shown in Fig. 17. The waste of power due to sliding the gun, instead of running it on wheels, is wholly unimportant where steam power is available, and ample bearing surface can be obtained to obviate the risk of the rubbing surfaces seizing.

Upon the system of mechanical loading, adopted at Elswick for guns mounted in turrets, the gun is revolved and depressed to a fixed loading position, where it is sponged and the charge rammed home by hydraulic power. The shot is brought up to the loading place on a small railway truck, controlled by a friction plate,

which clamps it to the rails whenever the truck handle is lowered. It is then run on to a hoist, which rises between guides against stops, and brings the shot opposite the gun muzzle ready for being rammed home.

The hydraulic tube rammer (Fig. 18) consists of a parallel tube in which runs a piston and tubular piston-rod. The head forms a sponge for cleansing the bore, and contains a self-acting valve which opens when pushed against the end of the bore, and discharges a strong jet of water within the gun. In ramming home the shot, this valve does not act, because it does not then come in contact with the shot, owing to the form of the rammer head. Nor does the valve open in ramming home the cartridge, the resistance being sufficient to bear the pressure against the bag without yielding. The same form of rammer has been made telescopic, to reduce the length, and has been found to answer well.

The jointed rammer shown by Fig. 19 is designed for positions where there is not sufficient space for the tube rammer. It consists of a flat link chain, on each joint of which is a wooden roller of a size to fit the bore of the gun. The joint pins project and engage notches in a double disc wheel or drum, the turning of which sets the rammer in motion. The disc wheel may be driven by a crank handle, or by a chain from an hydraulic cylinder, or in various other ways. A flexible tube may be employed to enter the gun with the rammer and drench the bore with water, or a pipe nozzle may be arranged to throw a jet of water into the gun when brought into the loading position. A wad pushed home with the shot in either case prevents the latter from running forward when the rammer is withdrawn.

By the arrangements described the following advantages are obtained: The loading operation is transferred from a confined space and exposed position in the port of the turret to a roomy and convenient place on the main deck, where the apparatus is completely protected;—the dimensions of the turret are greatly reduced, the minimum size that will inclose the guns being all that is necessary;—one man in the turret and one outside may direct and control all the movements of a pair of the heaviest guns, and may load and fire them without other help than that involved in bringing up the ammunition;—and finally, far greater rapidity of fire is attainable than would be possible by manual power. A popular objection to this plan is the alleged liability to premature explosions in loading, and the risk of self-destruction to which it is said the ship is thus exposed. Now the gun need not be depressed for loading to such an extent as to aim a shot below the water line, and

a hole made in the side armour in the line of the axis of the bore would enable the shot to pass clear out, without endangering the vessel, in the event of the accident occurring; but the fact is, that although premature explosions occasionally occur in firing blank charges in saluting, they are hardly known with shotted guns. An inquiry recently made by the English Admiralty has only elicited one case, and that a doubtful one, out of 250,000 rounds fired during a period of seven years. A risk so minute, and furthermore provided for by a special arrangement for drenching the bore of the gun with water in sponging, can hardly be considered an objection. Such as it is, however, it is entirely removed by the arrangement shown in Fig. 17, in which the loading gear is placed under cover of a gallery or hood slightly raised above the upper deck, and the gun is so little depressed when in loading position that a shot fired from it then would pass clear out, and glance from the upper surface of the armoured deck.

The time required to turn a turret from firing to loading position would be very short. The turret of the 'Devastation' makes a full turn in forty-five seconds, and this speed might easily be increased if desired. A dial and indicator hand may be placed near the lever controlling the engine which turns the turret, to enable the attendant to mark its position, and a stop similar to that shown in Fig. 20 will arrest and lock it without undue strain. A railway swing bridge over the Ouse, constructed at the Elswick Works, under the direction of Mr. Harrison, President, of 800 tons weight, and measuring 250 feet over all, is turned, brought up, and fixed in proper line, with great ease and rapidity by the adoption of very similar means. The gun may be placed in loading position on the slide while the turret is revolving, and since a fresh charge and shot can be brought up immediately one has been pushed home, and while the gun is being laid and fired, no time is lost. As a matter of fact, the whole operation of bringing to loading position, sponging, loading, and placing again in firing position a 9-inch 250-pounder turret gun, mounted experimentally on this plan, at the Elswick Works, has been effected in twenty-three seconds; and there is no reason why that time should be much exceeded even if the shot and gun were five times as heavy. Two or three loading positions may be provided round a turret as reserves, and to enable that one to be selected which will keep the turret port out of the line of the enemy's fire.

Fig. 21 represents a loading arrangement similar to that previously described, but adapted for a gun mounted "en barbette" behind an earthwork or iron parapet. Here the platform revolves

in place of the turret, and the loading gear and men working it stand in any convenient position in the rear, on a lower level than the gun platform, and completely protected by the parapet.

Fig. 19 shows the jointed rammer applied on a garrison platform in a manner in which it has been tried with success at the Elswick Works. In this case, as the rammer is fixed on the platform, there is no necessity for turning the gun to a definite loading position. The men engaged in loading remain under cover of the parapet, which may be of sufficient height completely to protect them as well as the loading gear; or the gun may be made to revolve sufficiently to allow of the loading being carried on, as in the last case, from a lower level within the parapet. On the present method of loading barbette guns by hand, the men have to mount upon the platform in full view of an enemy, and besides being exposed to shell fire, they become the targets for a rifle fire, which, owing to the precision and range now attained with rifles, will render it difficult to keep guns in effective action under such circumstances.

A plan suggested for the application of the hydraulic tube rammer to guns mounted in ironclad casemate forts, such as those at Spithead and at Plymouth, is shown in Fig. 22. Here the tube is overhead, and gives motion to a guided bar which passes out of the port, carrying at its end an ordinary rammer attached to it by a hinged stay. When done with, the rammer is thrown up over a hook above the gun, ready again for immediate use. In this case the gun is run in and trained to a fixed loading position, where the shot is raised on a hoist to the muzzle. The application of hydraulic power would enable these movements of the gun to be performed with ease and rapidity.

There is, however, no doubt more difficulty in the adoption of mechanical loading in existing casemate forts than in turrets or open earthworks. The size of artillery has so outgrown that of the existing forts, during the long time necessarily expended in their construction, that 38-ton guns have now to be mounted, if possible, in batteries originally intended for 12½-ton guns. But this fact renders it more imperative to dispense with manual power, because the heavier guns, while they further restrict the already limited space, require larger crews. The service by large numbers of men, of heavy guns closely ranged in confined casemates, tier upon tier, may tend to serious confusion in the heat of action; and the necessity of crowding men in time of war in isolated forts is of itself a grave evil. By substituting hydraulic for manual power for working the guns, nine-tenths of the men may be dispensed with, and the work may be done more coolly, more

rapidly, and more efficiently. Rapidity of fire is nowhere of greater importance than in the case of guns designed to prevent the passage of swift steamers past fixed batteries; and economy of men is a vital consideration in the defence of a coast so extended as that of the United Kingdom. It is said that already far more guns are mounted than can be manned. Modern artillery can only be worked by highly trained men, whom it would be impossible to produce upon short notice. Nor could a small force be made effective by activity in shifting to threatened points, for the attacks of steam fleets will be sudden and unexpected, and can only be met by preparation at all points.

The introduction of mechanical loading has an important bearing upon the question of the comparative merits of breech and muzzle-loaders. One of the chief advantages claimed for breech-loaders is that any length of bore can be given without increasing the difficulty of loading, and that, therefore, a higher duty can be obtained from the powder in a breech-loader than in a muzzle-loader of a length necessarily limited by the consideration of convenience of loading. It is also argued that men when loading the breech-loader are partly covered by the gun instead of being exposed at an open port as when loading the muzzle-loader. The mechanical methods described for loading at the muzzle neutralise these advantages, for it is evident that the stroke of the machine rammer may be increased without difficulty to meet any desired length of bore, and the loading gear together with the men working it are completely protected by the armour or parapet which protects the gun, whereas the shelter afforded behind a breech-loader by the gun itself is partial and inadequate. On the other hand, the breech mechanism of a heavy breech-loader involves complication both in construction and use, and the opening and closing of the breech requires considerable time, as may be inferred from the fact that the strain to be borne by the movable breech block of a 15-inch gun on Mr. Krupp's plan, assuming the powder pressure not to exceed 20 tons per inch, would be about 4,000 tons, and the weight of the block itself about 3 tons. Nor must it be assumed that the space required for loading a heavy breech-loader is inconsiderable. Room is wanted for the charge and rammer behind the gun and for the loading mechanism. In designing at Elswick a turret for two 70-ton breech-loaders of 15 inches calibre and 22 calibres in length, to compare with one for two muzzle-loaders of the same size, it has been found that whereas an internal diameter of 26 feet suffices for the two muzzle-loaders, a diameter of not less than 32 feet is

required for the breech-loaders. Fig. 23 shows the plan upon which the breech-loaders are arranged in this case, and it will be seen that space has been economised by making the rammer telescopic, and fixing it in such a manner as to be swung aside out of the way of the gun on recoil. The corresponding arrangement of the two muzzle-loaders is shown in Fig. 17.

The principle of sinking guns entirely under cover from horizontal fire behind any sufficient parapet, and raising them only to deliver their fire, possesses the great advantage of making earthwork defences available. Whatever thickness of armour be used, it may be predicted that it will in time become obsolete. All defences must yield to continued attack; an iron fort seriously injured could scarcely be made good before the end of a war, and only then at great cost. It is the especial merit of earthwork that it may be easily strengthened and adapted to new circumstances, and that it may be repaired almost as fast as it is destroyed. Two forms of gun-carriage, adapted for this system of protection, have been proposed by Major Moncrieff, M. Inst. C.E., the principle of both being the storing and utilisation of recoil. In the carriage (Fig. 24) tried and adopted by the English government, the gun on delivering fire and sinking raises a counterweight, the fall of which again lifts the gun when required. In the later invention the same object is sought to be attained by substituting for the counterweight the elastic force of air compressed by the recoil through the medium of water. Messrs. Sir W. G. Armstrong and Co. have endeavoured to carry out this later proposal for a 9-inch 12½-ton gun, mounted on a gun-boat of the Staunch type. The model will give an idea of the mechanical part of the apparatus. The air vessels, not shown, stand immediately in rear of the lifting cylinders. Careful investigation and calculations were made to adapt the volume and pressure of the air to the work to be done throughout the rise of the gun, and all unnecessary friction was studiously avoided. Fig. 25 shows the calculated work, and the corresponding air pressure at every point of the gun's motion. Notwithstanding every precaution, however, to avoid loss of power, it was found that the force of recoil was not efficient for the purpose. The principle was therefore abandoned, and steam pumps were employed for raising the gun, in combination with an arrangement for checking its recoil and descent, similar to that already described in reference to the hydraulic apparatus of slide carriages.

The economical value of utilisation of recoil is insignificant where steam power is available. Less than 1 lb. of coal is ex-

pended in raising the 12½-ton gun into firing position in the gun-boat, and 6 HP. enables it to maintain a continuous fire of one round per minute. The main object to be attained by the utilisation of recoil is to make of each gun-carriage a machine complete in itself, and independent of any connection with other machinery for producing the required power. In a system, however, of hydraulic gun-carriages, supplied with power from steam pumps, the connection between the carriage and the source of power is of the simplest kind, consisting only of a small pipe, which may be furnished with a stop-valve, and thus enable the power to be turned on or off, with nearly as much facility as a jet of gas. As there is no limit to the amount of power that may be conveyed, so there is no restriction of the height of cover obtainable—an important point in the employment of earthwork as a protection for guns, since the crest of the parapet may easily be cut down. Fig. 26 represents a design for mounting a gun of 12½ tons weight to be raised to firing position by hydraulic power. It will be seen that it lies a long way below the crest of the parapet, and protected from all shot whose angle of descent does not exceed 25°. A line in the drawing indicates the path of a shot entering the battery at that angle.

It is a question how far the principle of a disappearing gun is applicable to ships of war. In vessels of low freeboard, liable to have their decks frequently swept by the waves, an open barbette battery could not be worked in a rough sea. A proposition has been made that the gun should rise and fall through an aperture in the deck closed by sliding or hinged doors, to be opened only for the protrusion of the gun. Such devices may be objected to as being liable to be disabled in action, in which case the ship would incur great danger of sinking by the admission of water through the opening. Another plan has been suggested by Mr. Barnaby, viz., to inclose the gun in a thin plate turret, supported on and revolving with the gun platform, and carried up through the deck sufficiently high to allow the gun to rise under it, and deliver its fire through a port, as in an ordinary armoured turret. For vessels, however, like the 'Devastation' and the 'Fury,' carrying their guns low—as all first-class ironclads may probably continue to do to admit of the limitation of their surface and consequent weight of their armour—the turret appears still to afford the best means of carrying the guns. Where sail power cannot be dispensed with, as in a vessel, like the 'Temeraire,' designed for cruising, and a high deck is consequently a necessity, the case is different. Mr. Barnaby has designed for the 'Temeraire'

a barbette battery composed of a detached belt of armour supported at the level of the upper deck by a thin iron skin, which may be freely perforated by shot without losing its power of supporting the battery. In this case the battery, though open, is so high above the water level that a sea could scarcely enter it, and the advantage of all-round fire is realised in a situation in which a turret could not be used. The model represents a 38-ton gun designed for such a situation, to be worked on the disappearing principle by hydraulic machinery upon the methods already described, the water power being conveyed into the battery by a small pipe carried up from a pumping engine below through the armoured shaft which gives access to the battery. The jointed rammer is used for the purpose of sponging and of ramming home the charge, which is brought up the armoured shaft from below to the muzzle of the gun by a hydraulic hoist. The movable cover and deck are added to illustrate the adaptation of the system to vessels of low freeboard.

In the earlier applications of Sir W. G. Armstrong's hydraulic system, instead of the weighted "accumulator" now generally adopted, air vessels were used as accumulators, and they are still retained in some special cases, including those in which hydraulic machinery is employed afloat, when, from the motion of the vessel, the ordinary weighted accumulator would be inconvenient. It may be desirable to retain the weighted accumulator as part of the hydraulic system for land service; but in applying the system to sea service an accumulator can be dispensed with. Steam power unlimited in comparison with that required for working the guns is always available in modern ships of war, and the main engine boilers are reservoirs and accumulators of power so greatly exceeding what is required for the hydraulic machinery, that they may be drawn upon practically to any desired extent without affecting the main engines. An air vessel is undesirable on several grounds. It renders air-pumps necessary, and otherwise adds complication in construction and use. The regulation of the volume and pressure of the air requires constant attention, and it is apt occasionally to collect in pipes, and by its elastic action interfere with the control over the motions of the gun. It also renders the breaking of a pipe a more serious accident. On all these grounds it is contemplated to dispense with accumulators for hydraulic apparatus on board ship, and to pump direct upon the machinery, employing small steam engines of a form specially adapted to run when required at very high speeds, and so upon small dimensions to develop a very high power during the short periods in which it is required.

In conclusion, the Author desires to point out that this Paper is to be regarded as a *résumé* of the experience and practice of the Elswick firm, and not as a history of the subject. The labours of others in the same field are in some cases not even mentioned, and in others only very partially noticed. The names of Captain Scott, R.N., in particular; of General Clerk, R.A.; of Colonel Inglis, R.E.; of Colonel Shaw, R.A., and of Mr. Cunningham, as well as that of Major Moncrieff, are inseparably associated with the development of the mechanical appliances for working heavy ordnance, although the Author has not taken upon himself to define their respective shares in that development.

The Paper is illustrated by a series of drawings and diagrams, from which Plates 24 and 25 have been compiled.

[The Rev. J. White, M.A.

The Rev. J. White, M.A., observed it was stated by the Author that with the hydro-pneumatic carriage, notwithstanding every precaution to avoid loss of power, it was found that the force of the recoil was inadequate for the purpose of raising the gun. Now he had witnessed several rounds fired with an experimental 16-pounder hydro-pneumatic carriage made for Major Moncrieff at Erith, and had also seen more than thirty rounds fired from the 64-pounder hydro-pneumatic carriage, and no such difficulty arose, nor did it suggest itself to the minds of those present. Whether full charges or diminished charges were used, whether the firing was at long intervals or very rapid—and on one occasion he saw six rounds fired in five and a half minutes—the gun always rose readily to the firing position. On the occasion of the rapid firing the time of its rising was taken, and varied from eight to ten seconds. Moreover, eighty rounds had since been fired, with the same carriage, by the committee at Shoeburyness, with similar success. But the difficulty might have been anticipated on theoretical grounds; and he submitted that, upon theory, the recoil ought to be sufficient to raise the gun again. The recoil took place rapidly, more rapidly than it was desirable that the gun should rise, compressing the air in a very short space of time. Now the air at first was at a pressure able to sustain the gun; it was suddenly reduced by one-fourth or one-fifth of its volume, and the work stored up in so doing, overcoming all ordinary and legitimate friction, must be sufficient to raise the gun back to its original position when it was allowed a longer time.

But, it would be said, by the sudden compression of the air, heat must be generated, and when this was lost by radiation there would then be loss of power. Now from a practical point of view it might be a sufficient answer that this did not occur. To explain why it was so was a point of general scientific interest, and worthy of the attention of those who were able to throw light upon the subject. Air, by a well-known law, on rising from the freezing to the boiling point, expanded ·366, or rather more than one-third of its volume. Therefore when it was compressed by one-fourth it ought to gain 180° of heat, and proportionably for less diminutions of volume; and this heat would show itself by increased pressure over and above that due to the diminished volume. No such increase of pressure occurred in the hydro-pneumatic carriage, not even with the rapid firing, as he had ascertained by carefully examining the pressure-gauge after each shot. The reason appeared to be this: when the recoil took place the water was violently dashed up into the air vessel, the air became mingled with the water in globules.

and bubbles, and did not remain in a separate mass; and the coefficient of specific heat of water being four times that of air, the increased temperature generated in the air was taken up and rendered latent in very slightly affecting the temperature of the larger volume of water in which it was commingled. This was confirmed by an observation he made, that when the gun was slowly brought down to the loading position, by which the air was compressed in a volume by itself, the water not being splashed up into it, an increase of pressure beyond that due to compression took place. He should be glad if this explanation could be confirmed, or disproved. But the fact remained unaltered, however it might be explained, that no such difficulty occurred in Major Moncrieff's hydro-pneumatic carriage, nor was the force of the recoil prevented from being adequate for the purpose of raising the gun, unless that force were wasted by some extraordinary mechanical mismanagement.

Commander Dawson said this was essentially a naval question; and having had eighteen years' daily experience in the handling of heavy guns and carriages, and eleven years' experience in instructing people how to manage them, he might be permitted to offer some remarks on the Paper. Until a few years ago, none but the most rude and unmechanical contrivances for mounting guns were known on board ship. Not that naval men were altogether deficient in inventive genius; but in this matter their faculties had not been encouraged, and they had to receive the gun-carriages from their brethren in the army, who were not well acquainted with naval wants. Moreover, among sailors, there were strong prejudices against everything new, and the combination of these circumstances might account for the position in which the Navy had been placed. Happily it had been rescued from that position almost entirely by the exertions of Civil Engineers, foremost among whom was Sir William Armstrong, who had brought forward a number of inventions to lessen the mechanical difficulties in the way of handling guns. But, at the present moment, the plans devised by Sir William Armstrong and others had been set aside, and the carriages being made for the heavier guns were exclusively those devised by Captain Scott. One or two improvements upon his methods had been suggested, some of which were worthy of consideration. One of them was the substitution of a pivot racer for the turn-table (Figs. 7 and 8). He agreed with Mr. Rendel that the turn-table was an objectionable arrangement, but he was not sure that the proposed substitute would be found workable. It would have to be placed on a deck where various opera-

tions were going on besides those connected with guns, and would be subject on firing to a very heavy shock. If it could be worked, however, it would no doubt be an improvement upon the turntable. It would be remembered that Captain Scott proposed to do away entirely with the pivot bar in the port; the whole strain, therefore, would come upon the racers. Mr. Rendel proposed to do away with the tripper, but he did not know that its disadvantages were very great, or that this course would be attended with the same amount of safety under all conditions, as was at present secured. The problem was not, by any means, a simple one. A great variety of forces had to be dealt with. It was necessary to control the gun whilst moving it longitudinally, vertically, and laterally, while the platform was being tossed in every imaginable direction by the sea, and the ponderous metal upon it was subjected to the violent shocks occasioned by the explosion of heavy charges of gunpowder. The result was that a great number of expedients had been resorted to by a variety of Civil Engineers, soldiers, and seamen, before Captain Scott's plans had been adopted and comparative perfection was attained. He thought that Mr. Rendel might have included the name of Mr. Vavasseur, who had done so much in reference to gun-carriages, and whose methods had been adopted by several foreign Governments. An old gunnery officer, going on board ship and seeing the guns worked as in the present day, could not fail to be struck with the want of some improved method of loading them. Guns were now loaded in a very bungling manner, and if Sir William Armstrong or others could remove that reproach, they would accomplish a great work. He had no desire to discourage the efforts being made to apply hydraulic machinery to the working and loading of guns, but he thought if this plan were adopted it would be altered by its own inventor in a few years, so that any friendly criticism on its apparent defects would not now be out of place. With regard to the loading apparatus, it appeared to him that the port was exposed by moving the gun away from it to be loaded, a large hole being left through which the enemy's bullets might enter. So long as the gun itself was in the port, it acted as a stopper. It had occurred to him whether the land contrivance (Figs. 13 and 14) might not be applied to a gun on board ship, so as to avoid turning the gun away from the foe. Rapidity of fire was an important element in naval shooting. Seamen were in the habit of keeping their sights aligned upon a moving enemy during the process of loading, so as to be ready to fire, the moment the gun was loaded. In turning the gun away

to a fixed loading position, and bringing it back again to aim at the foe, he thought there would be a greater loss of time than the Author anticipated, not only in the mechanical operation, but in getting the gun-captain's eye accustomed to the new position. He should prefer to have the gun loaded in a moving position, so that the sights might be continuously aligned in the direction in which it was likely to be fired. If this could not be done, it would be simply a question of the balance of evils, and a choice of the less. With regard to the hydraulic carriage in Figs. 24 and 26, there appeared to be no alternative plan for working the gun in the event of the steam not being up, or of anything going wrong with the boilers. Naval men were in the habit of keeping their ships ready for action at all times, night and day, in peace and war. But the steam was not always up. The ship might be cruising under sail, or lying at anchor; and if an enemy suddenly appeared there ought to be some means of working the guns, even though imperfectly. No doubt hand-pumps could be fitted to the hydraulic apparatus to meet this objection. Then the plan appeared to be prepared for turrets only. He hoped to see the day when turrets would be no longer used, and when hydraulic machinery could be applied to broadside guns. He did not approve of the disappearing gun. Naval gunners would not view with favour a gun that had to be raised up, immediately fired, and then lowered out of sight and bearing. It might be necessary to train a gun upon an enemy for half an hour before getting a shot, during which time it must be exposed to the enemy's fire, and could not have the protection afforded by disappearance.

Major Moncrieff remarked that the subject of the Paper embraced a larger scope than its title indicated. It included not only the means for working, loading, and laying heavy artillery under various conditions on land and sea, but also the mechanical arrangements for the protection of the guns and gunners, and consequently it allied itself with the question of armour-plating and other defences, as well as with the important problems connected with iron vessels, which had to carry as well as to meet the powerful artillery now in existence, to say nothing of the still more formidable guns likely to be used hereafter. Mr. Rendel had supplied interesting information as to what had been done by the firm of which he was a member; but as to what he had said of the Moncrieff carriage and the system which bore that name he had an important correction to make. The Author had stated, with reference to the 'Hydra,' that "all unnecessary friction was studiously avoided;" and that "notwith-

standing every precaution to avoid loss of power," the energy of the recoil was not sufficient to bring down the gun into cover and raise it again. Now, when the Elswick firm were constructing a carriage for that gun-boat, as licensees under his patent, Mr. Rendel and he had different views as to the friction that would be imposed by small and tortuous water-passages between the recoil cylinders and the air-vessels, or accumulators. The two cylinders were about $9\frac{3}{4}$ inches in diameter, while the pipe leading into the air-vessel was only about 3 inches in diameter. This pipe had seven bends in it, most of them at right angles; and the current of water from each cylinder was made to impinge directly on that from the other, in a space not much larger than the pipe. It was obvious that this arrangement involved great water friction (especially where the two currents impinged), and that consequently there must be a waste of the force of recoil. The maximum recorded pressure in the cylinder was as high as 2,200 lbs. on the square inch, while that in the air-vessels was only 570 lbs. To the waste of recoil so occasioned, he attributed the insufficiency of the recoil of which the Author complained. That this explanation was right would be plain from the results obtained with another carriage, now at work, which had hitherto proved quite successful. Mr. Rendel, in a letter to him on 4th April, 1873, regarding the 'Hydra,' while her gun apparatus was still working on the method he preferred, reported as follows:—

"Fired five rounds, including the two proof-rounds of the gun. The valves worked perfectly, and we found the gun as manageable as could possibly be wished; but I was a little surprised to find that we still did not get it down to loading position with even the proof-charges. We have two clacks for greater security, and I took out one of them, but found it did not make much difference. I have carefully gone through every part of the machinery again, and have satisfied myself that it is not the valves that absorb the recoil to such an extent; in fact, the work done in recoil is insufficient, and I doubt our being able to get the gun down on firing, sufficiently to dispense with lowering it. This, however, is so easily done, that it seems to me a trifling objection. It has little or no effect upon the speed of firing, nor is the gun endangered, since it falls below the deck-line when fired, and can be dropped from the position it reaches into loading position in one or two seconds."

When the 64-pounder hydro-pneumatic siege carriage, now under experiment at Shoeburyness, was made for Major Moncrieff at Elswick, he intended the valve and passage to be of the following

capacity:—Valve, 9·4 square inches; passage between the valve and the air vessel 10 square inches. The valve and passage, however, were made according to Mr. Rendel's view, which gave for the valve only 2·6 square inches, and for the passage only 1·57 square inch. In this state the carriage was tried with precisely the same results as had been obtained in the 'Hydra'; that was to say, only about two-thirds of the full recoil. When the passage had been enlarged as much as the metal would permit, making it 3·51 square inches instead of 1·57 square inch; which was nearly 1· inch larger than the discharge valve, the desired result was obtained, namely, the full recoil of the gun to loading position. Eighty-two rounds had been fired with the 64-pounder siege carriage at Woolwich and Shoeburyness with complete success. The gun worked equally well with 8-lb. and 12-lb. charges, and the recoil was so ample that it had to be met by reduced air space, higher pressure, and full action of the throttle valve. That the recoil was not sufficient in the 'Hydra' to bring down and raise the gun was, he thought, fully explained by the form and arrangement of the pipes before referred to. It should be borne in mind that the table of pressures made at Elswick, and referred to in the Paper, was constructed on results obtained from the 'Hydra' carriage, in which the energy of the recoil was wasted by the mechanical arrangements adopted.

The Author seemed to think that the sole value of the Moncrieff system, so far as regarded utilising the recoil for raising the gun, consisted in its saving the very small quantity of coal required to raise the gun by steam. He begged to say that the advantages he claimed for the hydro-pneumatic system were of an entirely different sort. His object was to make each gun-carriage, when expedient to do so, self-contained, able to do its own work independently of any external or separate source of power, and further, always ready for action. He left it to sailors and to those who commanded large forts to state what they thought of guns which could only fight when the steam was up; which, on land, would require a steam engine or hydraulic accumulator to each fort or battery; and every one of which would be useless if the steam engine or hydraulic accumulator happened to be out of order, injured in action, or not working. How completely, and how simply, the hydro-pneumatic system accomplished its object might be judged from the fact that the 64-pounder siege carriage had the required amount of air pumped into it in the end of December, at Woolwich. It was taken to Shoeburyness in a barge and was moved about there, and on different occasions the gun

had fired fifty-six rounds since, and was now as ready for its work as ever. No loss of power in the compressed air had taken place, and no perceptible leakage of water. There was not, and had not been any air-pump at Shoeburyness, nor had he reason to suppose that one would be required, no matter how extended the trials might be. The first method which occurred to him for working the recoil system on board ship, after finding that the counterweight was inconvenient, was to employ steam power. On the 23rd May, 1868, he recommended the Admiralty to apply his recoil system in combination with steam power in preference to the counterweight. The method he then intended to adopt was to take the downward recoil by an hydraulic buffer, not perforated, however, like the service one, but with a solid piston, using steam power exclusively for raising the gun by hydraulic action. This was before he discovered that air was amenable to successful treatment in an air vessel or accumulator in direct communication with the recoil cylinders. He still, however, was of opinion that under certain conditions the absorption of the recoil might be advantageously performed without pneumatic reaction, provided the apparatus had an accumulator in contact with the pumps. He had recommended this arrangement last year, on being invited by the Admiralty to give designs for the barbette towers of the 'Temeraire.'

The Author seemed to confuse the disappearing principle with other methods of lowering guns out of fire. The peculiarity of Major Moncrieff's system was not merely that it effected disappearance, but that the gun retired of itself in the act of firing, and by the absorption of the recoil. In applying this system on land, the greatest advantages were sometimes to be obtained by the application of counterweight. In other cases, a head of water or accumulators were best; and at sea different alternatives were also at disposal. The manner in which the system of recoiling into cover was applied must, as an engineering operation, depend on the conditions which surrounded each application.

Mr. Butter—Manager of the Carriage Department at Woolwich—said he gathered, from the tenor of the Paper, that the Author intended rather to describe what was being done, and had been done at Elswick, than to give a general exposition of the subject, and it might therefore be out of place to allude to any omissions of reference to other important systems of mounting guns.

Mr. Harrison, President, said although the Paper referred principally to what had been done at Elswick, it was exceedingly important, in discussing a question of this kind, that as much

information as possible should be afforded with regard to other systems.

Mr. Butter remarked that the high character of the Author, and the undoubted excellence of the Elswick Works, were so great, that they could well afford to be subjected to a few adverse criticisms. Referring to a wrought-iron carriage made for a 70-pounder in 1865, the Author said it "led to an order being at once given for a 12½-ton gun-carriage on the same system, subsequently tried and adopted by the Admiralty;" but the fact was three carriages were ordered at the same time, one from Elswick, one from Captain Scott's designs, and one from the Royal Carriage Department. These three carriages and slides were tried in competition. The Carriage Department carriage and Captain Scott's were on board ship and were tried a month or two before the arrival of the Elswick carriage; therefore, whatever points of resemblance there were between that carriage and the other two, the credit must be given to Captain Scott and the Royal Carriage Department. It should also be borne in mind that smaller carriages, on the same types, had been made by Captain Scott and the Carriage Department, and had been tried previous to the order for the manufacture of the competitive carriages. After the trials a carriage was constructed in the Carriage Department as a pattern, which carriage embodied numerous points from each of the trial carriages; but the greater number were selected from Captain Scott's. It was, therefore, scarcely accurate to say that the Elswick carriage was adopted in its entirety. Next, the Paper stated that the Elswick compressor had "been adopted almost universally for naval use, and to a large extent for land service also." It was introduced into the land service, and was issued for a certain time; but its use had been abandoned, and whenever carriages, provided with the Elswick compressor, had to be altered, converted, or repaired, the hydraulic buffer was substituted. With respect to naval carriages, its adoption had never been extended beyond the 12-ton gun. The 18, 25, and 35-ton guns had been fitted with other compressors; and even the latest pattern of the 12-ton gun had not been fitted with the Elswick compressor, but with the bow compressor introduced by Captain Scott. Again, the Paper gave the entire credit of the rope-winch gear to Mr. Cunningham; but though Mr. Cunningham had several times laid his claims before the proper authorities, they had always been disallowed. The plan was, in fact, entirely worked out by Admiral Sir Cooper Key, and the officers of the 'Excellent,' in conjunction with the Carriage Department. With regard to the hydraulic buffer, the

Author said "The piston is perforated with small holes, and when recoil takes place, the water is compelled to pass through these holes from one side to the other, the friction thus caused arresting the recoil." Of course the friction caused by water passing rapidly through tubes was very great, but, considering the enormous pressure required to give the water a motion of from 100 feet to 400 feet per second, he believed that the checking force was due rather to that pressure than to the friction caused by the passage of the water through the tubes. In the case of the 35-ton gun at Shoeburyness, the highest velocity was 400 feet per second, and an enormous deal of work was expended in giving that velocity. The Paper then said, "The resistance varies excessively throughout the stroke, and the maximum strain, for which the strength of the parts must be calculated, is greatly above the mean." That of course was true; but it was stated in such terms as to lead to the supposition that it was rather a disadvantage, whereas it had always been looked upon as a positive advantage by those connected with its introduction. The second or third buffer constructed at Woolwich was, by a simple contrivance, made to give a constant pressure throughout the length of the recoil. There were four holes in the piston, and four tapering rods were introduced into the cylinder and passed from end to end, through the holes of the piston. The smaller ends of the tapering rods were attached to the front, and the larger parts to the rear of the cylinder, so that in the passage of the piston through the cylinder the holes were greatly contracted, and the velocity of the water was maintained. It could be made so as to oppose an increased resistance at the end of the stroke. Although this method answered very well, it was considered disadvantageous, for this reason:—The friction compressors gave rise to a jumping action in the front part of the platform; and there was always a tendency in the carriages to jump off the racers in front, when the Elswick compressor was used in connection with the service platforms, owing to the pressure of recoil being too great towards the end. It was therefore preferred to increase the pressure at first, and gradually to diminish it. With the present form of hydraulic buffer this tendency was never observed. The Author further states that "The buffer will not, of course, retain the carriage in any position on an inclined slide, nor will it restrain the movement of the carriage and gun within safe limits of speed under the influence of the motion of a ship; so that it cannot be used for sea-service, except in conjunction with a frictional break of sufficient power to control the gun when being run

out or in on its slide." One of the earliest forms of buffer was intended for naval purposes, and was exactly like that represented in Plate 25, Fig. 15, with this exception, that the valve, instead of being worked by a spring, was movable by a lever, and that there was a self-acting arrangement to cut off the recoil at any particular point. The valve might be closed at 4 feet, 4 feet 6 inches, or 5 feet, as the case might be. Some of those levers were not very well placed, and on the recoil of the gun they broke loose, closed the valve at 18 inches, and damaged the apparatus, which was never tried again. Still, it was a well-known fact that the buffer was tried in the presence of Admiral Key; and, had it not met with the accident to the levers, it might have been introduced into the Navy, and have superseded the Elswick compressor. It was quite capable of controlling the motion of the gun in any direction, of fixing it in any part of the slide, and of easing it out as nicely as any frictional compressor; but the breaking of the levers led to its being abandoned. In speaking of another carriage in which the hydraulic buffer or hydraulic press was used, the Paper stated that "immediately behind each block in the direct line of recoil are two hydraulic cylinders, for checking recoil and running the gun in or out." The form of buffer he had just described in connection with naval slides was also, when first designed, drawn in connection with portable hydraulic pumps, worked by hand; so that not only should the cylinder control the recoil of the gun, but that, by means of the pumps, the gun might be run in and out. Within the last few months plans had been worked out on that original design, in connection with the 35-ton gun. The ordinary means of running in and out, by Captain Scott's plan, of the endless chain, were so efficient that it was not considered necessary to complicate matters with any hydraulic arrangement. The common mechanical apparatus was preferred, and answered perfectly till the 35-ton and the 38-ton guns were reached, when it became necessary to contrive a plan in which there would be less loss by friction. The method adopted in the Carriage Department was simply to use hydraulic pumps, or jacks, which could be taken out, and be replaced by others, if an accident happened. This object, being constantly kept in view, rendered each gun independent of others, and secured for it a ready means of repair in case of its being struck, and an immunity from its being placed *hors de combat* from want of steam-power, either by the boilers being injured, or from steam not being available when it was required. The Author also contended that the muzzle-pivoting system, in use in the Royal Navy, "makes the carriage

however, high and topheavy, a disadvantage for naval service, which would become more serious with every increase in the weight of guns." The height of these carriages, however, did not depend on the weight of the gun. The 35-ton carriage was only $1\frac{1}{4}$ inch higher than that of the 18-ton gun, and this increase was in order to command a greater elevation. The maximum elevation of the 35-ton gun was 15°, whereas that of the 18-ton gun was only 13°. The extra size of the gun was provided for by allowing it to descend between the cheeks of the platform, so that the carriage did not become more unwieldy and topheavy as the weight of the gun increased. These guns, in the Navy, were taken to different steps in order to reduce the size of the ports; and on the middle step the ranges of the gun were from 2° depression to 8° elevation, and this comprised almost all the range required. It was only in extreme cases that greater depression than 2°, or greater elevation than 8°, was required. On each step, too, perfect control over the elevation and depression was obtained by a simple elevating arrangement, in this respect contrasting favourably with the plan proposed by the Author, which by placing the trunnions on the chase necessitated dealing with, probably, two-thirds the weight of the gun each time the elevation was changed, instead of dealing with the preponderance only as in the service pattern.

Mr. Siemens said, it might have occurred to the minds of many that too much attention had been directed to the mechanical arrangements for gun carriages, and that the tendency ought rather to be towards introducing fewer elements in the working of a large gun, and more particularly in the working of ordinary guns. No doubt some mechanical appliances were required for moving shot from the hold of the ship, loading, and using the ramrod, in the case of very large guns; but for ordinary gun practice he thought the machinery now proposed was of too complex a nature. In 1865 the laminar compressor, which had been perfected at Elswick, was coming into general use. It certainly was a most ingenious contrivance for multiplying the friction due to a moderate pressure, and for spreading it over a large surface, so as to produce a considerable aggregate amount of retardation without cutting action upon any portion of the surface, and without its being necessary to lubricate those surfaces. In 1867 he was invited by the Gun Carriage Department at Woolwich to advise them with respect to a project for improving that compressor. The contemplated improvement had in view to obtain the pressure between the laminæ of the Elswick compressor in a different way. It was suggested that perhaps, by setting up a powerful magnetic action,

friction might be produced to any desired extent. He told the authorities that such a plan was feasible, but that he knew too much about the disappointments in the use of electricity to recommend such a plan for practical application; and after consideration, he proposed the hydraulic reaction apparatus. His plan consisted simply of a cylinder with a piston and piston-rod connected with the gun, and a passage covered with an elastic valve, in order that, as the recoil took place, there should always be the same amount of resistance per square inch throughout the stroke, and that the gun might come to an absolute stand the moment that amount of power was consumed. General Clerk, with whom he had principally to deal, took up the idea warmly, and effected several modifications. He wished to do away with the tail-rod, which was unnecessary in his plan, in order to balance the area on both sides of the piston, and he accomplished this by filling the cylinder with water and air mixed. By that means an elastic resistance was opposed to the recoil action of the gun, and the first shock was greatly diminished. But this plan had its disadvantages; for, as the communicating orifice was invariable, it was never certain what amount of pressure would have to be dealt with, and as the thoroughfare was always open, the gun did not come to an absolute stop. The authorities at Elswick, who clearly perceived this drawback, had now introduced a plan not very dissimilar to that which he himself originally suggested, but going much farther than he then contemplated; for they proposed to drive the water by the recoil through a loaded valve into a separate cistern, whence it was to be forced by steam power into an accumulator to work the gun forward. This plan was also susceptible of the power of propulsion, a hand pump being applied to force the water from the front to the back of the piston: or the loaded valve might simply be raised while the gun-carriage was being pushed forward as usual. This was a matter of secondary importance; and he did not profess to judge of whether it would be better merely to have the valve, and to push the carriage forward, or to complicate the arrangement by the addition of a pump. The pump would, he thought, be found the preferable agency on board ship, especially in working heavy guns. General Clerk, in a pamphlet "On the Application of Hydraulic Buffers, to prevent the destructive effects of Railway Collisions," published in the year 1868, handsomely acknowledged the part which he had taken in the matter in the following words:—"In consequence of a suggestion made to me last year by C. W. Siemens, Esq., C.E., F.R.S., to try the effect of water to check the recoil of

heavy guns, I submitted to the Secretary of State for War a compressor or buffer on the above principle. It has been tried with guns varying in weight from only 150 lbs. up to 18 tons, and in all cases the results have been most satisfactory." But he had received no other acknowledgment from the Woolwich authorities; and by degrees his connection with the subject appeared to have been forgotten, thus furnishing an illustration of Major Moncrieff's disappearing principle. Major Moncrieff had also, in 1868, recommended the use of hydraulic resistance, coupled with air, instead of balancing weight, in working out his beautiful principle, and this improved arrangement had been modified again by the Elswick Company. The discussion as to whether or not the recoil would always be sufficient to bring the gun up to its position might be safely left between the Elswick Company and Major Moncrieff. *Primâ facie*, it certainly ought to be sufficient. The gun in descending gave off the whole force due to its descent to some reservoir which might be provided to receive that store of force. In addition to this there was the recoil; and recoil and descending weight ought surely to be sufficient to raise the gun to its original height. On the other hand, it must be considered whether, in retarding the descent of the gun sufficiently, it would not be necessary to throttle the passages to such an extent as virtually to destroy the surplus power. On this point practice alone could decide; but, certainly, the power itself, if it could be made available and be stored up in a compressor, ought to be amply sufficient to raise the gun again to its former height.

Vice-Admiral Sir Cooper Key observed that, as captain of the 'Excellent,' and Director of Naval Ordnance, at the time when the great changes were being made from wooden to iron carriages, and from smooth-bore to heavy rifled guns, he was the chief adviser of the Admiralty on the subject. He was cautious in introducing machinery; for sailors at that time had an idea that machinery was to be avoided in working gun-carriages. As an excuse for this hesitation, it should be remembered that the carriages were not then protected by armour plates. Men-of-war carried a large number of guns and men, and the authorities were cautious in introducing anything which might shake the confidence of the men in their arms. He had on two occasions nearly lost his ship from getting water in the cylinder—once on a lee shore, and once under heavy fire. In action a man might be replaced, but machinery could not be. The introduction of heavy guns, protected by armour plates, about the year 1865, changed his opinion and that of many others, and a great debt was owing to those gentle-

men who first pointed out the way to work the guns by machinery on board ships of war. Amongst them were Mr. George Rendel, Captain Scott, R.N., Colonel Clerk, R.A., and Mr. Cunningham. They were the pioneers in introducing iron gun-carriages, and the machinery for working them. Mr. George Rendel had, with but little practical experience of the difficulties attending the control and management of heavy guns in a sea way, instinctively appreciated those difficulties, and step by step had mastered them, as was shown by the various diagrams now exhibited, each of which represented a success, culminating in the proposal for lowering a gun while it was being loaded, and restoring it again to its firing position. It was scarcely worth while bringing forward the various claims to the different details now: that matter was discussed years ago, and there was plenty of room for credit to all who had their share in the improvement in naval gun-carriages. The Elswick compressor, in its simple state, was not now used in every naval carriage afloat; but the Author had shown that iron surfaces alone made an efficient compressor. When the iron compressor was first tried, water and grease were thrown over it, and many plans were devised to find out a weak point, without success. Mr. Rendel could claim the principle of using iron surfaces alone, which had been since adopted. No one could deny that the credit of the admirable plan for loading by hydraulic machinery was due to the Author alone; and that plan had this important effect, that it deprived breech-loaders of almost the only advantage they appeared to possess over muzzle-loaders. In addition to the advantages of greater rapidity of loading and simplicity of construction, muzzle-loaders might now be made of greater length with an important effect on their accuracy and penetrating power. Hitherto the length had been limited by the space that must be allowed in a turret for running the gun in to load. The system of lowering the gun proposed for the 'Temeraire' appealed forcibly to his reason. There might be structural objections to it, but it offered many advantages, among others, the reduction and reversing of the weight. He had been glad to hear Major Moncrieff make one remark, which left him and Mr. Rendel working in different directions. Major Moncrieff had said that his principle was the utilisation of the recoil for raising the gun from its lowered position. Mr. Rendel's principle, however, was simply the application of hydraulic machinery worked by steam power for raising the gun.

Major Moncrieff said he was not aware he had stated what Admiral Cooper Key had ascribed to him; if he had done so, he had certainly expressed what was not his opinion. His principle

consisted in utilising the recoil by lowering the gun. That was the first and most important point. The act of raising the gun was quite secondary to that of lowering. The latter point was the characteristic of his system.

Vice-Admiral Sir Cooper Key said if Major Moncrieff and Mr. Rendel worked out their own proposals, the advantages of both systems would be gained. It should be remembered that on board ship there was a large reservoir of power always ready; and he hoped it would soon be possible to get up steam in ten minutes or a quarter of an hour. He was glad to see a plan for applying that power in the simplest way, by means of hydraulic machinery, for raising the gun. In his remarks he had merely referred to the Paper, and certainly did not wish to ignore the successful efforts of Captain Scott, or the value of the hydraulic buffer to which Mr. Butter had referred. It was evident, however, that as guns and ammunition increased in size, and human strength was limited, machinery which a few years ago was simply advantageous had now become a necessity.

Mr. Lancaster said a great difficulty presented itself, namely, whether the muzzle-loaders should be retained, or whether they should be entirely abolished; because, without some such arrangement as the Author proposed, it would be impossible in modern warfare for any body of men, however disciplined, and however brave, to load a gun at the muzzle. The report on the battle of Lissa fully established the fact, that the Italian gunners were so galled by the riflemen of the Austrian fleet, that they, in many instances, dropped the shot overboard instead of attempting to ram it home, and that the guns were fired with powder only. All credit should be given to Major Moncrieff, Mr. Rendel, and the gentlemen connected with the Carriage Department for their various improvements. He, however, had never seen what he considered so practicable a method of muzzle-loading as that developed in the revolving rammers described in the Paper. He thought the Author had scarcely done himself thorough justice in the arrangement of the revolving turret for the breech-loading gun, for if he had been so disposed he might have applied the revolving rammer with equal facility to the breech-loading arrangement, and have considerably reduced the diameter of the turret.

There would not be any difficulty in moving side-ways the 4-ton breech-piece by the hydraulic arrangement, so that really, as far as regarded the convenience of loading, the muzzle-loader and the breech-loader would become convertible terms. On the other side it was to be urged that, in the breech-loader, there were many

more parts liable to fracture under the very heavy strain stated in the Paper. Another point which he would offer for consideration was, that in none of the schemes with which he was acquainted was there any tangible plan for seizing the gun under the circumstances of actual combat. For instance, if the turret were pierced, and the gear upset, what was there at present to prevent the gun from breaking loose and doing great damage? He was sure that this hint would be sufficient to lead to some easy means of seizing the gun being devised, so as to prevent any evil resulting to the ship from the gear being injured. In all other points, he could not too highly praise the loading arrangement described, which had, by the ever increasing weight of modern artillery, become the one thing necessary for war ships and iron forts.

Mr. S. J. Mackie said he had, from the outset of the important changes in modern armaments, watched the progress of events, and had exceptional facilities of witnessing and studying all the great experimental trials made in this country, as well as reliable sources of knowledge of what had been doing abroad. He confessed to being embarrassed both by the title and by the subject-matter of the Paper. The title was, "On Gun Carriages and Mechanical Appliances for working Heavy Ordnance;" but the matter dealt exclusively with the articles produced in the great ordnance factory of the Elswick Company, no distinct notice being taken of the productions of other firms, or of the designs of any other inventors. It must, however, be admitted, that at the Institution the subject of modern mechanical appliances for working heavy ordnance should be discussed as a distinct branch of modern engineering; and he wished to say something on the general subject of other inventions of this class not noticed in the Paper, as well as on one or two of the specialities of Sir William Armstrong's firm.

The first person to propose wrought-iron gun-carriages for rifled guns was Mr. John Hughes formerly so long of the iron works at Millwall, and now the manager of extensive iron works in Russia. The casual reading of one of the first passages in the Paper—and, indeed, even a more careful reading by any one not intimately versed in the history of the subject—would lead to the impression that wrought-iron carriages were originally designed by Sir William Armstrong, to overcome difficulties experienced with his own guns. Such, however, was not the case.

In the Paper it was stated that, "The first break or compressor, designed at Elswick to meet these requirements, was tried in the year 1864, by the Ordnance Select Committee, on a

70-pounder timber carriage." Now it was in June of that year (1864) that Mr. Vavasseur designed and constructed, for the late Captain Blakely, R.A., the wrought-iron carriage and slide for the 11-inch 15-ton steel guns, of which the model was on the table (Plate 26). One of eight of these wrought-iron carriages and slides, which were made for the Peruvian Government, was tried at Woolwich in February 1865, the gun for which it was produced being a 500-pounder, firing 55 lbs. of R.L.G. powder; and yet it was stated in the Paper that "in 1865"—much later in the year than February—"Sir W. G. Armstrong and Co. designed and constructed a 70-pounder wrought-iron naval carriage and slide, in which they introduced an improved 'compressor,' made entirely of wrought iron." Now the weight of this 70-pounder was 75 cwt. (under 4 tons), and its firing charge was 10 lbs. Thus it was evident that in 1864, while Sir William Armstrong was making wooden carriages, Mr. Vavasseur was making wrought-iron ones; and that in 1865, when Sir William Armstrong began to design wrought-iron carriages, he had not even got as far as the lightest of heavy artillery (7-inch guns) whilst Mr. Vavasseur had advanced to what were the equivalent weapons to the 10-inch naval guns, which even now constituted the bulk of the armament of the ships of the Royal Navy and of the English forts, and the designs of which were not even submitted to the Government for approval by the Woolwich Gun Factories before 1866. Still further, he believed he was strictly correct in saying that these Blakely-Vavasseur 11-inch gun-carriages were the only wrought-iron gun-carriages for land service that had ever gone through the ordeal of actual fight —these having been used against the Spanish fleet in 1866, when it attempted to bombard Callao.

Turning now to details, he wished to draw attention to the fact that in those Blakely-Vavasseur carriages of 1864 "the cheeks are of double plates riveted on each side of a frame of iron," very similar to the leading types of carriages now made at the Elswick Works, and long before Sir William Armstrong had advanced from 70-pounders to 250-pounders, or before there was any record of his having adopted this system. Again, in respect to Sir William Armstrong and Co.'s wrought-iron carriage for 15-ton guns, progress having of course been made from the 75 cwt. (4 tons) of 1865, there was this statement in the Paper: "The two points of novelty, to which attention may be directed, are the method of training the platform, and the substitution for the usual tripping rollers under the carriage of a number of grooved rollers, permanently running on the slide, and sufficient to bear the shock

of recoil." An inspection of Mr. Vavasseur's model (Plate 26) would show that these points, which were so markedly brought forward in the Paper, were anticipated five years before the date of Mr. Rendel's patent of 1869, in which (No. 2,796) he claimed as one of his improvements that "it consists in making the carriage to run upon the slide or platform on permanent rollers, so as not to require to be lifted for running in or out, and the rollers may be flanged or grooved, or made to run in guides on the slide beams." Thus it was difficult to discover the novelties of these two points, which not only existed in the model referred to, but of which pictorial illustrations were printed and published in the "Illustrated London News," in the volume for 1865. Moreover, it was not correct to ignore the skilful inventions of Captain Scott, R.N., who had devoted much skill to the subject, and with great success, and who in 1865 was also trying, on board one of H.M.'s gun-boats, a naval carriage for a 7-inch gun, the checks of which were, however, only single plated. Nevertheless the fact remained that he too was in advance of the Elswick Company in the application of wrought iron to gun-carriages. Returning to the history of the subject, he took the Armstong compressor, as now put forward. No acknowledgment was made by name of the Ericsson compressor. It was simply spoken of as the American compressor. It was well known, however, to have preceded all other designs in this direction. The substitution of iron friction plates in the slide, in the place of friction plates compounded of iron and wood, was dwelt upon in the Paper as an essential particular in this, that "as it is self-acting no accident can happen from its being forgotten" to be put into gear. Mr. Mackie differed from the Author in respect to the Armstrong or the Ericsson compressor being, strictly speaking, self-acting, although that term might be admitted in a fashion, and that with it no accident could happen—the latter point being one which any one who had seen heavy guns worked either ashore or afloat would not admit. At sea it was particularly dangerous for the seamen gunners to follow the compressor lever, on the carriage along the slide, when the gun was being run out for firing, or had to be checked in a sea way. The Elswick-Ericsson compressor was self-acting only when the carriage was run out to the full extent of the slide. If this was not done the toe of the compressor lever was not caught by the tripper fixed to the slide, and the gun recoiled without any compression on the compressor. Again, unless the compressor lever was put down by hand, when the gun was run out, the gun recoiled 8 or 10 inches without compression, as the com-

pressor was not put into action until the tripper had been struck, and so a violent momentum of the gun and carriage was thus attained, the sudden checking of which brought a dangerous strain upon the fighting bolt. This arrangement was also manifestly inferior to the V-shaped outside plates introduced by Captain Scott, and now adopted generally in H.M.'s Navy. Personally, he did not consider either of the foregoing systems approached the screw-shaft compressor introduced by Mr. Vavasseur, in 1866, in efficacy, certainty, and regularity of self-action, or in ease and convenience of handling. He had seen the Vavasseur compressor worked with complete success, when attached to the 7-inch steel gun (Plate 26), both on shore and afloat. The weight of this gun was 5 tons, of the projectile 115 lbs.; the charge of P. powder was 30 lbs., and the weight of the carriage slide 54 cwt. In the naval trials, accorded by the Admiralty in 1869, on the recommendation of Admiral Key, he was struck with the ease, certainty, and precision with which such a heavy gun could be controlled, when the ship was rolling, by the mere motion of a man's arm as he stood watching the seas and the gun at the end of the slide. The primary advantage of this system was that it was strictly and always self-acting; and, secondly, that the compression commenced with the recoil itself and gradually increased. The running out of the gun liberated the compression; and the running in of the gun, whether by recoil or by gravitation, put the compression on, whatever might be the position of the carriage on the slide. A steel screw-shaft was carried along the middle line of the gun-slide, free to revolve in either direction. On this screw-shaft a nut attached to the gun-carriage moved either way in a longitudinal direction forwards or backwards. As this nut could not turn round, the screw-shaft was forced to do so by the weight and momentum of the gun and carriage brought upon it through the securing nut. At the fore end, this screw-shaft was keyed to a cone-head forming part of a friction clutch. When the gun was run out the pressure of the nut on the screw-shaft liberated the clutch, and the cone-head on the shaft revolved freely: when the gun was run in the clutch was brought home, and drove a drum against break-straps as the screw-shaft turned round by the force of the nut, and thus gradually brought up the gun as the carriage and nut receded along the screw-shaft. Over the drum of this friction clutch were two break-bands; one of these was permanently set to the service charge; the other was put on to various degrees, as might be required, to meet the exigencies of battering and other charges heavier than the service

charges. The gun and carriage were in this way never out of control, whilst that control could be increased to any desired extent. All this portion of the compressor, therefore, was always ready for action. If the gun was run out it acted automatically; if the gun was run in it did the like. It wanted no watching, no tending. Unlike the Elswick friction slides, no sudden strain could ever be brought upon it. Still further, the control of the gun was certain and assured by the minimum amount of human energy, and necessitated no following of the gun along the slide. At the rear end of the screw-shaft a break arrangement was attached, having connected with it a side-bolt with holes for the insertion of a handspike, a quarter turn of the bolt clamping up the friction break and stopping all motion in the gun and carriage, and this at all angles of inclination of the slide. To show the high estimation entertained of this admirable and simple system, Mr. Mackie quoted two or three short passages —one from the Official Report of the Austrian Commission on the Vienna Exhibition of 1873, as follows:—"The perfect self-acting working of the front compressor and the possible control of the gun while running out by the rear break are facts which are of the highest importance in the case of naval guns requiring a light and precise serving." The second was the opinion of Captain Simpson, the U.S. Naval Commissioner to Great Britain, who stated in his recent Official Report to his government, that "the most interesting gun-carriage in England is that of Mr. Vavasseur." The French Artillery Commission also said that "no other system gave in so complete a manner control over the movements of the gun."

Captain Selwyn, R.N., said the gun-carriage was in itself a small matter; it might take a variety of shapes, and be more or less mechanical in proportion as the ships were more or less guarded by armour, but after all it constituted no great change in principle. That which would, however, constitute a most important change was referred to in the Paper, and he quite agreed that "The principle of sinking guns entirely under cover from horizontal fire behind any sufficient parapet, and raising them only to deliver their fire, possesses the great advantage of making earthwork defences available. Whatever thickness of armour be used, it may be predicted that it will in time become obsolete. All defences must yield to continued attack; an iron fort seriously injured could scarcely be made good before the end of a war, and only then at great cost." What had been so well said of earthworks could be as well said of water. Water and earth were two

species of armour which might be relied upon to resist all kinds of shot, even if Mr. Krupp were successful in producing shot weighing a ton. If, then, a carriage could be devised which would render available to the fullest extent on land the cover of the earth, and at sea the cover of the water, a great change would be brought about, and all other changes of detail would disappear in importance in comparison with this one point. The great feature of Major Moncrieff's carriage was that there was no reasonable limit to the depth of cover it might be made to give. It also possessed the important qualification that it did not deprive the gun of individuality, which must be retained whatever else was sacrificed. In proportion as the number of guns was diminished it was important that they should be protected from possible damage, particularly from such damage as would affect several guns at the same time. At sea there were mechanical difficulties in the way of loading a gun under water and bringing it up to fire, but they were not insuperable, and were in fact not so great in their consequences as the putting of such heavy dead weights as turrets of 300 to 400 tons on a deck. But all-round fire had now been superseded. No doubt guns had been mounted on floating gun-carriages, but he did not think that landsmen would view them with great pleasure as domiciles, nor would they like to be deprived of all means of locomotion directly they found the boilers unfit to bear the pressure for which they were designed, as were many of the boilers in the Navy. He was both surprised and pleased to hear that Admiral Sir Cooper Key expected steam to be got up in from ten to fifteen minutes, for he had paid some attention to that subject, and considered it was impossible to heat many tons of water to the boiling point in less than from twenty-five minutes to three quarters of an hour. In a Field or other circulatory boiler on land, it might be done in less time, but he did not think it possible in a large marine boiler, subject to the changes of water level inseparable from a moving platform and the disadvantages of salt water. Major Moncrieff had pointed out that a gun lowered was in quite a different condition from a gun which lowered itself. The one took time; the other did not. The raising of the gun again also took time, and was quite a different matter from what was required on such a carriage as was advocated by Major Moncrieff. Next he pointed out that increased machinery was necessary, on the principle advocated by Mr. Rendel, and that the individuality of the gun was thereby sacrificed. Admiral Sir Cooper Key had said that no one could deny that the method of hydraulic loading was due to

Mr. Rendel, but Captain Selwyn had seen a drawing of the same contrivance in Major Moncrieff's office three years ago. How far great minds might have jumped to the same conclusion he could not say; but he presumed that constant communication might have afforded information on both sides. As regarded the hydro-pneumatic apparatus, which Major Moncrieff preferred, success was the best answer to all comments, and he was quite sure the Elswick firm would be among the first to hail the fact of success, and would carry out the changed conditions under which the gun succeeded. The gun might then be lowered beneath the water-line, and made to return to broadside ports, when a larger number of guns could be carried. There was no greater fallacy than to fancy that there would be any difficulty in carrying to sea the heaviest gun that could be made. Many hundred tons of coal could be shipped, and 100 tons of coal would occupy more space than any gun at present proposed. As regarded the system of sponging out, he thought the Author, rather overrated the softness of a cartridge full of powder, when he imagined that a valve could not possibly be pressed back by it. With proper sponging, there was no danger of premature explosion unless the gun was seriously fissured. He had never seen a case in which this had taken place with shotted guns. He considered that loading the gun at an angle was a doubtful advantage. To bring a gun back to a certain depression after firing at a certain elevation was a waste of time, unless done automatically, as in the carriages devised by Major Moncrieff, where, whether the gun was fired at elevation or depression, it always returned to the position desired. Mr. Lancaster assumed that the gun could not be loaded without great exposure of the men; but in a naval engagement the smoke of action rapidly prevented accurate aiming. Besides, the torpedoes lately introduced would prevent close combat being sought as it formerly was, and the fighting must be at long ranges, when the chance that a shot would hit any particular place would be small.

Mr. Rendel remarked that Captain Selwyn had commented on the hydraulic carriage as though it had been a hydro-pneumatic carriage.

Captain Selwyn said there was so much actual similarity that he could scarcely separate the systems. If such a system were adopted, the useless expenditure of enormous sums on fortification would be spared, the Navy would again be seaworthy, and the skilled artillerymen would be less often 'expended.'

Sir W. Armstrong observed that he would rather have left the

conduct of the discussion, from the Elswick point of view, altogether in the hands of his partners; but having been so much associated both with hydraulic machinery and with gunnery, it might appear strange if he remained altogether silent. The Paper exemplified the strong tendency existing at the present day to extend the use of machinery in substitution of manual labour. Economy of labour was highly important in all cases, and it was the especial function of the engineer to promote it in every possible way; but it was peculiarly important in the operations of war. England could ill spare the number of men necessary for warfare conducted upon old-fashioned principles. On the other hand, the British were pre-eminent for mechanical resources, and it behoved them to draw as much as possible upon those resources, and to do as much fighting as possible by machinery. It was not a question of comparative advantage whether machinery was used or not, but a matter of absolute necessity that it should be used. The weight and magnitude of ordnance had of late so enormously increased that it was no longer possible to manage it by hand. There were now 38-ton guns to deal with, and the time was at hand when guns would be double or three times that weight, so that there was no alternative but to use machinery for them. In fact, it was impossible even to find standing room for the number of men that would be required to work monster guns of that size; and if men could be employed in such great numbers, there would be a most inconvenient crowding and interference one with another. This evil, already experienced with large guns mounted in forts, would be enormously increased with guns of much greater magnitude. The only question was as to the kind of power best adapted for the purpose. It was natural, perhaps, for him to advocate hydraulic power, as, in his opinion, no other power was so simple, so safe, so manageable, and so precise in its action, and therefore so well adapted for the purposes in question. Moreover, its facility of transmission, admitting of the source of power being put in any convenient place where it was safe and protected, was much in its favour. As had been remarked, this subject had an important bearing upon the question of breech-loading *versus* muzzle-loading. Hitherto, every advance in the size of guns had favoured the breech-loading system, because the heavier and larger the gun the longer it had to be made, and with every increase of length there was an increased difficulty of loading from the muzzle. By machinery it was as easy, or nearly so, to load a long gun as a short one, and that difficulty therefore was overcome. Even if breech loading were to

be adopted, for guns of the size now contemplated, it would equally be necessary to apply machinery. There would still be the same ponderous shot to lift and ram home, and, moreover, it would be necessary to apply mechanical power to work the breech, since the parts of it would be so enormously heavy that it would be impossible to work them by hand, except by very slow motions, so slow as to be incompatible with the necessary rapidity of fire. The advantage, therefore, in point of simplicity, would hereafter be more than ever in favour of the muzzle-loading gun. He did not, however, agree with a remark to the effect that the application of machinery would remove the only objection to muzzle loading. Large guns were subject to destructive erosion of the bore, caused by the rush of gas past the shot, and also to a troublesome erosion of the vent, requiring frequent repairs, and deteriorating the gun; for the rush of gas to the vent-hole had a tendency to set up a guttering action in the bore round the base of the vent, and the gutters thus produced were liable to degenerate into fissures. In breech-loading guns the plan of coating the projectile with a soft metal was almost in universal use; on firing, the soft metal was crushed into the grooves, and at the same time that rotation was produced the windage was entirely arrested. Therefore breech-loading guns were not liable to that scour which was so injurious in the case of muzzle-loading guns. The vent, also, in breech-loading guns might be placed in the movable closing block, so that whatever injury was caused by the rush of gas through it was confined to a part that could be replaced, leaving the body of the gun altogether uninjured. These defects of the muzzle-loading system, if irremediable, would form a strong argument in favour of breech loaders, especially as the larger the gun the more serious was the erosion. There was every prospect, however, of both these difficulties being removed in muzzle-loading guns. Captain Noble, of Elswick, had been for some time past experimenting upon the practicability of giving rotation to the projectile, in the muzzle-loading gun, by means which would at the same time entirely stop the gas. This had been found perfectly effectual in the 12-ton gun, the only one in which it had been tried. The method was now being adapted to a larger gun, and he had no doubt it would be equally successful. The arrangement was as follows:—A steel ring was fitted upon the back of the shot in such a manner as to have a travel of about $\frac{1}{2}$ inch. The force of the explosion drove the ring home, and in doing so crushed a copper hoop between the shot and the sides of the bore, by which means the copper entirely filled the grooves, just as in the case of

the breech-loader they were filled with the soft metal coating of the projectile. In that way the gun was perfectly gas checked, and by the same apparatus the necessary rotation was produced. The stoppage of the vent was effected by a steel plug screwed into the body of the gun immediately over the copper vent. This remained a fixture, but was capable of easy removal in case it should be desired to fire by the ordinary process The interior of the plug was bored out and screwed, so that another plug could be fitted inside of it. The inner plug had half the thread cut away as in the screw of the French breech-loading gun, so that it went in at once and by a quarter of a turn was rendered fast. Inside the inner plug a plunger worked in a cylindrical chamber, into which a primer representing the common friction tube was dropped. In the centre of the plunger there was a pin to fire the primer by detonation, and surrounding it a steel gas check, which, when the powder was exploded, expanded so as to stop the escape of gas. The charge was fired by striking the external head of the plunger. The recoil of the plunger was stopped by a shoulder. The manner in which this apparatus originated was interesting. Captain Noble had made extensive experiments upon the force of fired gunpowder. He had occasion to fire powder in a close vessel so as to imprison the gas, which exerted a pressure of about six thousand atmospheres. It was necessary for this purpose to fire with a close vent, for with the slightest aperture the gas would have escaped, and in doing so would have eroded a hole in the apparatus. This was an exceedingly severe test, but it succeeded perfectly, and Captain Noble was led to adopt the plan for firing large guns. These two things, viz., the means of stopping the gas in the bore, and preventing the erosion of the vent, taken in combination with the mechanism already described in the Paper, would, he thought, in future place the muzzle-loader on a par with breech-loaders in regard to all the advantages that had been claimed for the latter, while, in other respects, the muzzle-loaders would continue immensely superior. He therefore confidently expected that the great guns of the future would be muzzle-loaders.

Colonel Jervois, C.B., stated that he agreed generally in the remarks of Sir William Armstrong with regard to the advantage to be attained by the application of hydraulic power in the working and loading of very heavy guns in different kinds of batteries. There were various modes of mounting guns in fortifications, either behind ordinary earthen parapets or iron shields, on the barbette system, in casemates, in turrets, and behind segmental iron shields. In all these cases, the application of

hydraulic power would no doubt facilitate the loading and traversing of the heavy guns now being introduced. The proposal for applying hydraulic power, however, to the loading and working of guns was by no means new. The matter was some years ago referred to the military authorities of the day at Shoeburyness, as to whether such facilities were required; they then came to the conclusion that it was not necessary to introduce such refinements in the working of heavy artillery. Since that time, however, much heavier guns had been made, and probably the same authorities might now come to a different conclusion. As regarded the several proposals for the loading of heavy guns in casemates, there was one which he believed would not be found to answer. The projecting arm, from which the sponge was worked, would be liable to be shot away, besides having other disadvantages. A proposal had been made, which he believed would be found to work well, for exhausting the air in the gun, and loading it on a pneumatic system. With respect to the application of hydraulic power to the barbette system, the contrivance for turning the gun round and loading it from the rear might no doubt be serviceable. The ordinary barbette gun, however, exposed over a parapet, was inadmissible, unless the battery was at a considerable elevation above the sea. With the accuracy of fire now attainable by rifled ordnance, a gun in that position, unless at considerable height, was liable to be silenced almost immediately. This led to the proposal for raising and lowering the gun, so that it might be protected except at the time of firing, which might be done either by a counterweight, as originally proposed by Major Moncrieff, or by hydraulic power. It was a question, however, whether, in cases where heavy artillery was used, the working of a gun on a turn-table behind a segmental iron shield with two or three ports in it, was not preferable to raising and lowering the piece. One object of the segmental shield system was to get increased lateral range, combined with protection both in front and overhead, without incurring the expense of a turret. It might be introduced at a cost of £6,000 or £7,000, whereas a turret would cost about £30,000. The question of raising and lowering heavy guns was in a great measure one of expense; supposing a considerable saving were effected, it might be worth while to submit to the disadvantages of raising and lowering the gun; if only a small sum could be saved, he would rather work the gun and fire it from the position in which it was to be used. If it cost £6,000 to mount a gun behind a segmental iron shield giving 120° lateral range, it would

be better to adopt that plan than to spend the same amount of money in raising and lowering the gun. With regard to turrets, the difference of expense would be so great as to be a very important element in the consideration. He did not find that other nations adopted the plan of raising and lowering guns. When lately at Metz and Strasburg, he was surprised to find how little attention the Germans paid to the protection of their guns on the ramparts of the new fortifications. They were satisfied with running a gun under a bomb-proof or covered casemate on a rampart, then firing it and running it back again. When asked why they did not adopt the Moncrieff system, which he thought was well adapted to the lighter kinds of guns used in land fronts of fortifications, the answer was that no protection could be given to guns worked on that principle, unless some hard material, such as concrete or masonry, was adopted, and in that case men would be killed by splinters. Every proposal for the application of hydraulic power to the working of guns generally should be thoroughly considered, from whatever source it came.

Captain Noble stated his opinion that the placing of carriages upon permanent rollers, objected to by Captain Dawson, was a great improvement, especially for land service. It saved two men at an important point in the working of the guns. In the naval service it might naturally be asked, What would become of a gun so mounted in a heavy sea? But by means of a compressor, such as that designed by Mr. Rendel, the power was readily obtained of adding a friction far more than was represented by the mere dead weight of the gun and carriage upon the slide, and the gun would be much more manageable under those circumstances. With reference to the exposure of the men, due to the port being left open, when the gun was in the loading position, the constructors of the Navy had come to the conclusion that the great and essential point was to protect the life of the vessel; the next point was the preservation of the guns, and last of all the protection of the crew. A man or two could be easily replaced, but the guns that could now be mounted were necessarily few, and the loss of one or two of them might result in the loss of the ship. Moreover, when the gun was fired, the port was immediately turned from the enemy towards the loading position; and one of the principal objects of the hydraulic arrangement was to have as few men as possible in the turret, not more than one or two men per gun. It therefore effected a saving of numbers, and it greatly diminished exposure as compared with the system of loading by hand. The time taken in turning the port to the loading position, there being

generally at least two such positions, was very short. As a matter of fact the turning could be done while the gun was being placed in position for loading, and in an actual experiment with a 12-ton gun at Elswick every operation, from one period of firing to another, was accomplished in twenty-five seconds, which was faster than guns should be fired. It was said that some of the carriages were obsolete, or, at all events, superseded by better patterns. That criticism chiefly referred to the compressor, for which, however, he had a strong preference. The type of carriage described, including the compressor, had been adopted nearly in its entirety by every nation in Europe. Even when English guns were objected to, the English types of carriages were considered as beyond praise, and were all but universally adopted. As remarked by Colonel Jervois, the applicability of hydraulic power to large guns had been considered at Elswick, as well as among the Royal Engineers, for the last thirteen or fourteen years, but it was only recently that, on the guns becoming so large, Mr. Rendel felt it was right to introduce it. Even in existing fortresses, where it might be inconvenient or expensive to introduce hydraulic power in the most improved form, it might still be employed as a subsidiary power for raising shot, and so dispensing with a large number of men. Experiments had just been tried at Woolwich with charges of 130 lbs. of powder, and others were to be made with 140-lb. charges. With such charges it was obvious that means were necessary to raise and transport the shot in casemates, such as those at Portsmouth and Plymouth. For all such purposes hydraulic power was the most convenient, and it in no way prevented the use of manual labour when the other was incapable of application.

Captain HEATHORNE said the question to be considered was whether a gun was worth protecting to the uttermost, or not at all? Men, and guns of small calibre, could be easily replaced, but it was otherwise with large and heavy guns The difficulties in the way of working and efficiently protecting heavy guns showed the necessity of the greatest possible consideration in the construction of the required machinery. The two difficulties he had experienced were, first, the loading of the guns that were protected, the space allowed for their protection being generally restricted; and, secondly, in getting sufficient room to work a gun so as to make use of its best efforts both in vertical and lateral fire. The question of a minimum embrasure had been warmly discussed. That system had been tried with guns of the largest calibre, and, coupled with the breech-loading system, had received great con-

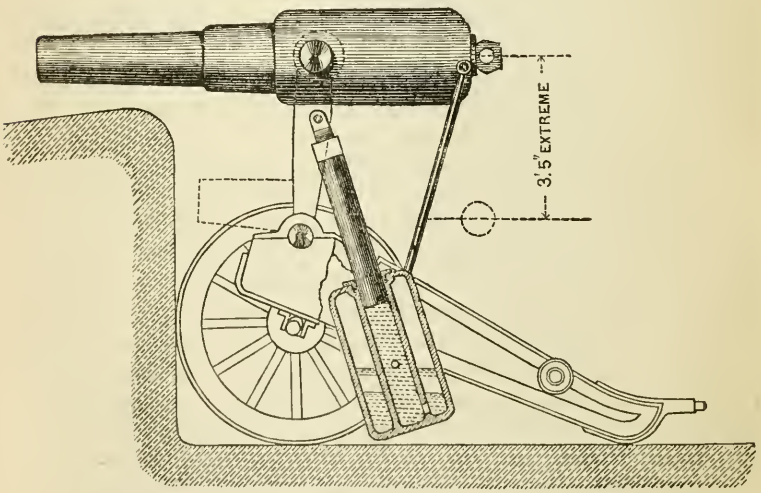
sideration from foreign military engineers. The question of loading was one of still greater difficulty than that of protection, and more worthy of consideration. Manual power was now ineffectual; the arc described by the muzzles of the present large and long trunnion pivoting guns, changing from positions of elevation to depression, was now so large, that the gunners at the muzzle engaged in loading and serving the gun had to occupy different positions for each case, one position being some feet higher than the other. Moreover, in working muzzle-loading guns at a port, the rammer stock was so long and inconvenient that it might easily be seized by boarding parties, and thus the work of the gun be stopped. The embrasures of the present day were so large that riflemen or mitraille would soon dispose of a heavy gun. In a fight in which he had been himself engaged, the size of the embrasure enabled the enemies' riflemen to kill the non-commissioned officer laying the gun before it was once discharged, and eventually to silence the gun. About five years ago he sent in to the War Office and the Ordnance Select Committee, a plan of a pneumatic arrangement for loading as being the only means he could think of to obviate the difficulty; but it met with the usual fate, and his plans were returned. He was glad to hear that the method was now coming into consideration, and he believed it would be generally adopted.

Mr. G. W. Rendel, in reply, said it would be useless to enter into the numerous questions of priority of invention raised in the course of the discussion. One might very fairly conclude that those gentlemen who had devoted their remarks so exclusively to suggestions of want of originality, had found little to criticise in the engineering aspect of the plans he had brought under the notice of the Institution. Mr. Rendel gladly addressed himself to the task of answering the remarks of Mr. White, who had commenced the discussion by a strictly engineering criticism, and those of Major Moncrieff, who followed in the same line of argument. Mr. White, referring to a statement in the Paper as to the experience of the firm in attempting to apply the principle of the utilisation of recoil by hydro-pneumatic action, as proposed by Major Moncrieff, objected to that statement, and suggested that either they had arrived at their conclusion on theoretical grounds, or that there had been some "extraordinary mechanical mismanagement." He could not admit either of those explanations. On theoretical grounds, or as a general proposition, it certainly could not be contended that the force of recoil was insufficient, because the work done by a gun or

other weight in falling from a height was clearly the exact equivalent of the power required to raise the weight to the same height. One balanced the other theoretically; and the force of recoil, however small a proportion of it might be realised, ought to be sufficient to turn the scale. Nevertheless, it might easily happen that the work of recoil actually stored and realised fell considerably short of that required to meet the various sources of waste involved in the practical application of mechanism to lift and lower the gun. Mr. White argued that the recoil was, in practice also, sufficient, because he had witnessed firing from a small experimental gun, and from the 64-pounder siege gun, and the gun rose after every round very readily, with both full and reduced charges. That, however, was not the question. It was, whether the gun descended from firing right down to the loading position against such a pressure as would raise it to the firing position when required. Unless it did so, the object of the arrangement failed. No doubt the gun would rise after recoil from whatever position it reached, because the pressure of the air in the air vessel was adjusted by pumps, in the first instance, and prior to firing, at such an amount as would raise the gun from any point of its path of descent. Of course, therefore, it might be predicted that it would rise after recoil from whatever point it reached; but the question was—Did it come down to the loading position? In the experiments at Elswick, it was found necessary to increase the charges beyond the then service charge, namely, 8 lbs., before the gun came down from the firing to the loading position. Major Moncrieff attributed that result to the want of area in the valve passage between the air vessel and the ram-chamber. That passage was first made 2 inches area (not 1·57 inch as stated). The maximum velocity through it was of course only momentary, because, as the gun descended, its speed of recoil rapidly diminished. The passage was quite short, and the loss of force it involved would not greatly exceed that due to the head required to produce the velocity through it, which was in itself undoubtedly high, but when compared with the head corresponding to the pressure at which the apparatus was worked, it was not so. The mean pressure at which the apparatus was worked corresponded with a head of between 1,000 and 1,100 feet; the head required to produce the maximum momentary velocity through the valve when it was of 2 inches area was 64 feet. After the first trial it was enlarged from 2 inches to 3½ inches, but the subsequent trials did not show any appreciable improvement. At Woolwich a slightly better result was obtained, but there were several causes to

account for it. In the first place glycerine, which would act as a lubricant, was used with the water, and the packing of the ram and possibly even the friction through the passages might be less. Then the gun had been fired a good deal with large charges, and the surfaces would no doubt work smoother. Another cause might partly account for the difference, but he would allude to that when speaking of the 12-ton gun. The fact, however, remained that at least 8-lb. charges were required to bring down the gun from the firing position to one in which it could be loaded. In comparing this result with that obtained with the 12-ton gun of the gun-boat 'Hydra,' due account must be taken of the differences between the two, which were most important. In the 64-pounder the rise and fall were about 3 feet, 3 feet 5 inches being an extreme with the buffer compressed. The rise and fall of the

Fig. 1.



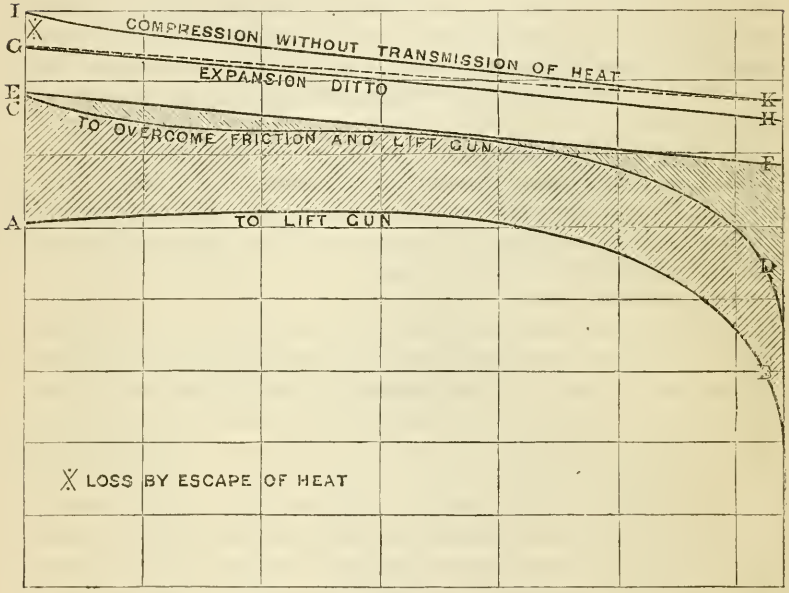
12-ton gun in the gun-boat were 6 feet, or double that of the 64 pounder. There was therefore double the amount of work for the force of recoil to do on that account alone. Moreover, although he could not admit that the arrangement of the gun-boat apparatus justified any such term as "extraordinary mechanical mismanagement," yet, undoubtedly, from the nature of the case, it was not so favourable as that of the 64-pounder in respect of friction, an all-important point where only a limited force was available. The gun-boat drew but 6 feet of water, and the problem was to get a 12-ton gun and the apparatus for working it within the vessel

below the water line. It would be obvious that the problem was not an easy one, and that it was not likely to be accomplished in a manner to avoid friction so completely as in the case of the 64-pounder siege-gun apparatus. Even if the same duty had been realised in the gun-boat as was realised in the 64-pounder, it could only be expected that the gun would come down 3 feet. A fall of 6 feet was required in order to load it, and therefore the object could not be accomplished by the utilisation of recoil. That was consistent with the results actually obtained in the case of the 64-pounder.

He proposed now to point out some of the causes of loss which he conceived to account for the ascertained result. The first and most obvious was that which he had mentioned—friction. In the case of the gun-boat apparatus the actual friction had been carefully measured. The pressure in the air vessels was first lowered until the gun would fall very slowly, it was then increased until the gun would just rise. In both cases the motion was so slow that there could be no question of friction of water in the passages. It would be obvious that the difference between the two pressures so ascertained was twice the amount of the friction involved, because on the descent the friction would aid, and go in diminution of, the pressure, and in the ascent it would impede and be an addition to the pressure; in fact it would be plus and minus. That experiment, therefore, supplied an exact measure of the friction. In the diagram the horizontal measurements were portions of the stroke or volumes of the air vessel; the vertical measurements were pounds pressure per square inch. The line A B showed at every point of the stroke the net theoretical pressure required to raise the gun. C D showed the same with the addition of the friction measured as already explained. The area between the two lines represented the work lost by the friction of the rise or fall, the whole friction to be overcome by the force of recoil being twice that amount. The second source of loss was the want of coincidence between the air-vessel pressure available and the pressure required actually to raise the gun at each point of the stroke. The line E F showed the pressures in the air vessel as the air expanded in putting up the gun. The difference between the lines E F and C D was all loss, because it would be observed that while there was only just enough pressure at one point to raise the gun, there was at others an excess; yet it was impossible to diminish the pressure and retain the power of putting the gun up from any point of the stroke. Theoretically, it might be argued that it

was because the excess where it occurred might go in producing velocity and momentum to carry the gun over the point where the power was deficient; in fact, it might be argued that the line E F might be drawn as a mean through the line C D. Practically

Fig. 2.



that was impossible, because first of all, owing to the motion of the vessel, the gun was liable to be arrested at different parts of the stroke; and if, while rising, it stopped where there was no excess of power, it could not be again started. Further, in actual practice at sea, from the motion of the vessel the gun was sometimes lively, and it required a considerable excess of power to give perfect control over it, and to enable it to be put up with safety.

Thirdly, there was the loss by heat. Mr. White had correctly pointed out that where the water was violently injected into the air by the recoil of the gun, as in the 64-pounder, the water, owing to its high specific heat, and to the great weight of it in proportion to the weight of air used, would absorb the heat of the air with a very slight rise in its own temperature. But he concluded that here was therefore no loss. Now, in order that there might be no loss, it was clear that the air must receive back again on its expansion, either from the water or from some other source, all the heat which it gave out on compression; and, inasmuch as the

replacing of the gun was done tranquilly and without intermixture of air and water, and at the same time done pretty rapidly, he did not think one could count upon getting back that heat, or, at any rate, only a very small portion of it.

Fourthly, there was the loss due to work done in setting in motion the whole apparatus, the carriage in the one case, and the entire gun-boat in the other, and not in compressing air. In the 64-pounder field carriage a considerable jump took place when the gun was fired; the wheels rose, and there was indication of a considerable amount of work done upon the carriage. That, obviously, was all lost; it was not stored up; it was work done and lost, and so much off the available force of recoil. He had before mentioned that he should allude to a source of loss which he thought would account for some difference of the results observed at Elswick and Woolwich with the 64-pounder siege gun; and this was the loss to which he then referred. If the platform was weak, or yielding and soft, it was obvious that there would be more work done upon the carriage than if it were hard and rigid. There was probably some difference in this respect between the experiments at Elswick and at Woolwich. Again, the carriage was made fast, for the purpose of firing, to a post driven in the ground, by a rope or chain passed over the axle. Such a mode of firing must allow more or less motion to the carriage, and hence also some room for variation in the results. Nevertheless, it required 8-lb. charges to make the gun drop properly from the firing to the loading position. It could not be used with the reduced charges which were essential in siege guns; and he believed all military men considered that curved fire, attainable only by very reduced charges, was of the utmost consequence for siege guns.

Summing up the various sources of loss, the following results were obtained. The friction of the rise and fall of the apparatus, which had to be met by the force of recoil, stated in foot-pounds amounted to about 92,000. The second source of loss mentioned, viz., the want of coincidence between the effort required to raise the gun and the effort available under the law of expansion of the air—that and the excess of power for raising the gun required to work the apparatus safely amounted to about 30,000 foot-pounds. Thirdly, the loss by transmission of heat amounting in the 12-ton gun apparatus to about 11,000 foot-pounds—the smallness of which amount was due to the fact that the air vessels were made large in proportion to the displacement of the lifting rams—so as to avoid the heat difficulty. The whole amounted to 133,000 foot-pounds of work. Against this there was a force of recoil in

the 12-ton gun with maximum, or battering charges of 50 lbs. of powder amounting to about 100,000 foot-pounds, and with the ordinary service charges of the gun of about 80,000 foot-pounds, less, of course, whatever work, instead of being stored up in the air vessels and made available for raising the gun, was expended in giving motion to the whole apparatus. Allowing a moderate amount for the work thus lost, and not stored, there was a large deficiency of power available to raise the gun from the loading to the firing position—something like one half.

The friction of water in the passages had been alluded to by Major Moncrieff. The maximum velocity through the two pipes, between the air vessels and lifting presses, was 20 feet per second. Through the short, single pipe, connecting these, the maximum velocity was 30 feet per second, and through the clack valve it was 40 feet per second. These velocities were of course only momentary, and diminished rapidly as the gun descended. He did not say that the friction at those points would be represented by the mere head that would produce those velocities, but taking the heads as giving some sort of proportionate measurement, they were respectively $6\frac{1}{4}$ feet, $14\frac{1}{2}$ feet, and 25 feet. Taking even five times those amounts as the loss due to the respective velocities, and comparing them with the head which corresponded to the pressure at which the apparatus was worked, the proportion would be seen to be very small. The apparatus was worked at a pressure of 750 lbs. per square inch, or about fifty atmospheres, which corresponded to a head of upwards of 1,700 feet. It might therefore be inferred that the loss by friction through the passages, especially considering that it only lasted a short time, was not proportionately large, and did not seriously absorb the force of recoil.

In the case of guns heavier than the 9-inch gun, and especially of guns dropped below the water line, so as to be loaded under cover of the water, and then raised high enough above the water line to deliver their fire clear of waves, it was obvious that a greater height than even 6 feet would be required, and consequently still more work of recoil in proportion to weight of gun would be wanted to make the system available. It need hardly be stated that large guns required to be dropped lower on account of their greater diameter. But there was no more work available, because with guns of all sizes the velocity of recoil, with corresponding charges, did not vary much, and the work of recoil was about the same proportion of the weight; and it was the weight of the gun which, *cæteris paribus*, regulated the amount of work to be done in raising it through any given height. This, therefore,

was the position: it could not be expected to work any gun by ordinary charges through more than 3, or at most 4 feet rise and fall with the force of its own recoil stored up, and it would require probably not less than from 10 to 12 feet rise and fall with large guns, or guns mounted to be loaded under cover of water, on that plan.

The insignificant economical value of utilisation had been admitted by Major Moncrieff when he said that he attached no importance to the saving of the very small quantity of coal, but that the object of his invention was to make each carriage able to do its own work independently of any separate source of power, and always be ready for its work. The Author had said almost the same thing in the Paper. He did not dispute the desirability of making every gun an independent machine if it could be done consistently with meeting other important conditions; but if in attempting to accomplish this by storing and utilising recoil, it became necessary to supplement the force of recoil by an external source of power, the object was not accomplished, and the complications and defects of two systems were united with the full advantage of neither. The model exhibited of the carriage for the 'Temeraire' was purely hydraulic and not hydro-pneumatic. By dispensing with storing and utilising recoil the air vessels were got rid of, and there was no limitation of power. The enormous advantage was thus obtained of having a power, and that the most suitable and perfect of its kind, available for other operations besides the raising of the gun, such as raising the shot from the magazine in the bottom of the ship to the muzzle, training the gun, and for all the operations of loading. The recoil in the 'Temeraire's' carriage was arrested, controlled, and regulated for different charges and conditions, by an arrangement almost exactly similar to that shown in Fig. 10.

It was objected to the hydraulic system, in the course of the discussion, that it could not be used unless steam was up, and that a central pumping engine might be disabled and all the guns of a fort or ship thus be put *hors de combat*. But in ships of war, of the type now generally used, steam was practically always up. The vessel depended exclusively upon its steam in action, and it had a number of smaller engines for ventilation and other purposes. The objection, therefore, had not much weight. Taking, however, the extreme case of a vessel at anchor without steam up, there could be no difficulty in adapting the pumps so that they might be worked by a portion of the crew on such an emergency.

He regretted if, in the course of the discussion, he had said

anything that could be construed into a neglect of the claims of other labourers in the same field, or over-assertion of his own. In regard to Major Moncrieff's claims in particular, since they had been made the subject of public controversy, he wished to say a few words conciliatory and not critical. He said, "Although I have felt it necessary to point out in detail in reply to Major Moncrieff and Mr. White the technical reasons which compel us to regard Major Moncrieff's hydro-pneumatic system as unavailable in those cases in which we especially contemplate the use of the disappearing principle, yet I wish to state here that we recognise the fact that it is chiefly due to his labours that the disappearing principle has been brought so prominently into notice. Our firm is willing, therefore, to treat his claims on a broader basis than that of his patents, and if in our hands the principle shall become to us a commercial success we shall be willing to concede to him a reasonable participation in the benefits. If we cannot agree on terms we shall be very glad if the President of the Institution, Mr. Harrison, will kindly intervene by his advice in bringing about a settlement of the question."

NOTE.—Subsequently to the discussion, Mr. Rendel transmitted to the Editor the following extracts from Reports of 1866 and 1868, which are necessary for explaining some of the statements in the Paper and in the Discussion:—

Extract from "The Times," 28th May, 1866.

"We understand that the reports on the competitive gun-carriages that have lately been under trial on board the iron frigate 'Bellerophon,' forwarded to the Admiralty by Captain A. C. Key, C.B., and by the Committee, presided over by Captain R. A. Powell, C.B., are both in favour of the iron carriage and slide sent for trial by Sir William Armstrong, in preference to any other of the carriages that have been on trial. The reports also recommend that Sir William Armstrong shall supply all carriages required for the present mounting of 12-ton guns on the broadsides of any of Her Majesty's ships."

Extract from Letter from War Office to Messrs. Sir W. G. Armstrong and Co., dated 26th February, 1868.

"The self-acting compressor, the invention of a member of your firm, has been tried with the heaviest guns and under the most adverse conditions, with complete success.

"Although the use of wrought iron as a material for gun-carriages has frequently been proposed (and with some promise of success by Captain, now Colonel Simmons, Royal Engineers, as far back as 1852), it remained for you to show in what manner the best principles of construction should be applied to this purpose; and though further experience has necessitated modifications in several details of your first proposals, manufacture is now being carried on in the Royal Carriage Department on the same general principles as then shown."

March 17, 1874.

THOMAS E. HARRISON, President,
in the Chair.

And

March 24, 1874.

GEO. ROB. STEPHENSON, Vice-President,
in the Chair.

The discussion upon the Paper, No. 1,385, "Gun-Carriages and Mechanical Appliances for working Heavy Ordnance," by Mr. G. W. Rendel, occupied both evenings.

March 31st, 1874.

THOS. E. HARRISON, President,
in the Chair.

No. 1,393.—"On the Fixed Signals of Railways."[1] By RICHARD CHRISTOPHER RAPIER, Assoc. Inst. C.E.

IT is a trite axiom, that two solid bodies cannot occupy the same space at the same time. The duty of the railway signalling engineer may be said to be to endeavour to prevent two bodies, which are moving at high velocities, from seeking to violate this law of nature.

Wherever the possibility exists of one train coming into collision with another—as, for instance, when a goods train has to come out of a siding about the time an express train is due, timely notice should be given by signal as to which of these operations should be first performed. From this necessity the present systems of Fixed Signals on Railways, and the interlocking of switches and signals, have been gradually developed.

The demand for increased signalling facilities is not confined to this country, but has arisen in other European countries also; and distant colonies are now inquiring for, and purchasing, the most finished appliances for these purposes.

In endeavouring to trace the progress of fixed signals, it must necessarily be that many varieties of arrangement and many inventions may escape the attention of the Author; but his purpose is to describe the actual steps which have contributed to present results, and in so doing he hopes to demonstrate that the systems which now appear to be indispensable are not fanciful complications, but are really simple in character, and form a complete series of safeguards, to provide against almost every variety of error on the part of the persons in charge of the switches and signals.

Against error on the part of those in charge of the trains, the only safeguard is to be found in the complete adoption of the

[1] The discussion upon this Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

absolute block system, and of means for enabling the drivers to observe signals well in advance.

The absolute block system consists in dividing the line of railway into longer or shorter lengths, and by means of telegraphic and fixed signals allowing only one train at a time to be on the same length. This method of working railways was proposed in the year 1842 by Mr. (now Sir William) Cooke, Assoc. Inst. C.E.; and during the thirty years which have succeeded, various modifications of Sir William Cooke's plans have been tried on different railways, with the result of finding that nothing short of the absolute block system, then recommended by him, will meet the present requirements of English railways.

Under the "absolute" block the signalman at station A is not permitted to send a second train to station B until he has received a signal from B that the first train has arrived there. When a train starts from A to B, the signalman at A telegraphs to B, "Train on line," and B acknowledges the signal, and virtually replies, "Yes, train on line; keep your signal at danger until I tell you." This is called the "absolute" block.

Under the "permissive" block system it is simply permitted to signalman B to block signalman A in the event of anything occurring at B which may render that course desirable. If, however, a train has just left A, of course the message comes too late to enable A to prevent the train running into the obstruction at B.

The permissive block has been well tried on the principal railways, and is preferred by some because it enables the trains to be sent one after another with greater rapidity; but it affords very little protection, and it is now generally agreed that intermediate signal stations must be erected on all lines of constant traffic, so as to make shorter lengths, rather than allow several trains to be on a long length at the same time.

When the distance between any two stations is so great as to cause the line to be blocked for too long a time, the best plan is to interpose one or more intermediate signal stations. The distance apart of the signal stations seldom exceeds 4 miles, and is often only $\frac{1}{4}$ mile, the average being $1\frac{1}{2}$ mile.

In 1863, a Paper by Mr. W. H. Preece, M. Inst. C.E., on "Railway Telegraphs," gave an account of the methods of signalling by telegraph from one station to another.[1]

The Author now proposes to describe the Fixed Signals on railways by which the signalmen are enabled to communicate

[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. xxii. p. 167.

with the drivers of the trains, also the apparatus for controlling the movements of signals and switches, and the facilities at present for allowing fast trains to pass slower trains.

The subject naturally divides itself into the following heads:—

1. Early railways opened without signals.
2. The early types of signals, and their intended indications.
3. The semaphore signal, which is now becoming the universal type.
4. The use of distant signals.
5. At a later stage signals alone were found insufficient without the concerted action between switches and signals ensured by interlocking apparatus.
6. The various stages of interlocking apparatus.
7. The necessity of protecting facing switches against movement during the passing of a train.
8. The facilities now afforded, by complete signalling and locking apparatus, for working passing-places for enabling slow traffic to get out of the way of faster traffic.
9. Various matters connected with railway signalling which are not yet established axioms, but some of which seem likely to become so.

The Stockton and Darlington, the Newcastle and Carlisle, the Liverpool and Manchester, and other early railways, were opened without any fixed signals.

About the year 1834 an approach to fixed signals was in use on the Liverpool and Manchester railway. On the top of a post, the height of an ordinary lamp post, was placed, by means of a ladder, a red or white light. This signal was for night use only. Mr. Edward Woods, M. Inst. C.E., designed a more permanent arrangement, substantially as in Figs. 1 and 2; but without the vanes for day use. So little attention was, however, then given to the subject of signals, that no practical steps were taken until the opening of the Grand Junction railway in 1838, which was furnished with the signals shown in Fig. 3, similar ones were erected on the Liverpool and Manchester. This signal consisted of a circular, or D-shaped board, fixed on a spindle with a handle to turn it through an arc of 90°; a lamp for night was fixed either on the same spindle, or on the post which formed the support of the moving spindle. The disc towards the driver indicated "danger," and when turned on edge "safety."

Mr. Woods' signal, Fig. 1, became adopted in Scotland, and many are still in use in that country.

In 1838 Sir John Hawkshaw, Past-President Inst. C.E., designed the movable rails with disc signal, Figs. 4, 5, 6, 7, and 8, for the Manchester and Bolton railway. The disc signal was connected to the movable rails, and, with them, was set in motion by the handle and balance-weight acting upon the bevel-wheels and eccentric, so that when the switches were open to the siding the disc was presented "full on," whereas if the switches were open to the main line, the edge only of the disc was seen. If any train came out of the branch whilst the switches were set for the main line, the wheels were elevated by an inclined rail, and were thrust laterally by the high guard-rail, Figs. 7 and 8, so as to push the carriages on to the main line and prevent them getting off the rails entirely.

On the Newcastle and Carlisle railway, in 1840, red disc signals (Fig. 9) were put up. The disc, 4 feet in diameter, was fixed on a revolving pole with a handle to turn it, and the exhibition of the signal was considered to block both lines; the early practice on that line being, that if a train were standing in the station on one line, any train arriving from the opposite direction had to wait outside the station until the first train left.

In Fig. 10 a type of signal is shown which the Author believes was peculiar to the Stockton and Darlington railway.

On the Stockton and Hartlepool the first signal consisted simply of a candle placed in a window of the station to indicate that the driver was to stop to take up passengers, and the absence of the candle implied that he might proceed without stopping. When the Stockton and Hartlepool was opened in 1842, the three junctions, Fig. 11, were deemed to be sufficiently protected by a pointsman's box, and a pole 30 feet high, fitted with a pulley at the top and a rope, by which a wooden disc or a red lamp was hauled up, as a signal that trains might pass round the curve which joined the Stockton and Hartlepool lines, and that trains to or from Ferryhill might not pass. When the disc was down, the trains might pass from Stockton or Hartlepool to or from Ferryhill, but not round the curve. This signal was constructed by Mr. John Fowler, Past-President Inst. C.E., then resident engineer and manager of that line. No fixed signal was provided to cover the contingency of two trains arriving at the junction for Ferryhill at the same time; this was considered sufficiently simple to be within the personal direction of the pointsman.

On the Great Western railway a ball signal, Fig. 12, was introduced about 1837. The ball drawn up to the top of the post,

after the manner of a high-water signal, indicated "safety," and a common stable lantern was hooked on at night instead of the ball. The kite signal, Fig. 13, was made about the year 1838. It consisted of a light iron frame, fixed on the top of a post, and covered with canvas mounted on rings on the top bar of the frame. A double string served to spread out the canvas on either side to indicate "danger" or "caution," or to reef it entirely to indicate "safety." These signals, though favourites with Mr. Brunel, gave place in 1843 to the forms shown in Figs. 14 to 21.

In Fig. 14 the signal consists of a cross-bar 8 feet long, and 1 foot wide, and a disc, 4 feet diameter, fixed at right angles to the cross-bar. The presentation of the cross-bar to the driver indicates "danger," and the disc (15) "safety." It is worthy of note that, whilst the Great Western introduced the disc as a "safety" signal, other companies adopted it as a "danger" signal. At junctions, double arms and double discs were used to govern the branch line, Figs. 16 and 17.

In 1847 a distinction was made on the Great Western between signals for "up" and for "down" lines. The plain cross-bar, Fig. 14, was appropriated to the up line, and for the down line the cross-bar was fitted with end pieces or horns pointing downwards, Figs. 18 and 19. A signal, Figs. 20 and 21, to block both up and down lines was made with end pieces pointing up and down.

About the same time the caution signal, Fig. 22, was adopted; the arrow painted red and pointing to the rails indicated "danger," and the green side of the arrow, Fig. 23, pointing from the rails, "caution," or "go slowly." These arrows referred only to the line next to which they were placed. The practice used to be to keep the danger signal on for five minutes, then turn the arrow to caution for five minutes more, and finally the main signal, Fig. 15, to safety. Lamps for night were not at first used upon all signals on the Great Western, but were introduced gradually.

For some years the semaphore signal has been in course of application on the Great Western, and in a short time the signals above described will have become quite extinct on that railway. They are, however, still preferred to the semaphore on the Bristol and Exeter railway.

When the London and South-Western was opened to Southampton, say in 1840, the form of signal, Fig. 24, was introduced by the late Mr. Albinus Martin. It consisted of a light iron framework, 5 feet diameter, covered with canvas or tin, but with a

semicircular aperture in it extending to within 6 inches of the outer edge. This disc was mounted on a central pivot fixed on a post. The periphery of the disc was grooved for the reception of a cord. A double cord was attached to the frame of the disc, and brought down round an adjustable pulley, near the ground, so as to be within convenient reach of the operator, like an ordinary window-blind cord, but on a larger scale. This signal was much used as a cover to shunting operations, as follows:—If the closed part were turned to the left as in Fig. 24, it indicated that the left-hand road only was blocked; if the closed part were to the right, as in Fig. 26, it indicated that the right-hand road was blocked. If the closed part were turned to the top, as in Fig. 27, it indicated that both lines were blocked, and if the disc were turned bodily, with its edge to the driver, it indicated that both lines were clear.

The evolutions above described were only of use during the day: for night use two lamps with red and green glasses on each were fixed on spindles on either side of the post, to enable the shunters to show danger to either or both lines of way. This movable disc was a favourite shunting signal for nearly thirty years, but is now giving place to the semaphore.

The form of signal shown in Fig. 28 was also introduced about the same time, as a signal for one road only; and it was for a long time the standard type of distant signal on the London and South-Western railway. The disc has an aperture on one side and a lamp is fixed under the disc and on the same spindle. The presentation of the disc with the closed part to the left hand shows danger to an approaching train; and when the edge of the disc is presented, safety is indicated. A driver coming from the opposite direction sees the *open* side of the disc to *his* left hand, and so is informed that the signal does not concern him. On this line, as on the Great Western railway, double discs were used for branch lines.

About 1840, on the London and Brighton, the Lancashire and Yorkshire, and other lines, the signal shown in Fig. 29 was generally used.

Another variety is shown in Figs. 30, 31, in which the discs are mounted on a horizontal axis, carried in bearings fixed on the top of a post. This has been used since 1846 as a distant signal in distinction from the semaphore type which was at first introduced on some lines for a "home" signal only.

Figs. 32, 33, 34, represent the "danger," "caution," and "clear" signals respectively used on the Caledonian.

The above may be said to include all the types of early signals, although many varieties have been made, with slight and even fanciful differences. All these early signals, often puzzling and sometimes conflicting, are now fast giving way to the simpler and more definite semaphore signal.

Semaphore Signals.

About the year 1841, Mr. C. H. Gregory, Past-President Inst. C.E., designed and erected at New Cross the semaphore signal, Figs. 35, 36. This was an adaptation of the old form of semaphore used for telegraphing to short distances; and has proved to be, perhaps, *the* most important step in the development of railway signals.

The drawing is a sketch of the first signal erected, except that one arm only is shown in the drawing for the sake of greater clearness. At first the lamps, with red, green, and white lenses, were worked by a separate handle; but soon a pair of bevel-wheels were added, so that one handle worked both the blade and the lamp; also levers connected by rods were substituted for pulleys connected by wire ropes, and counterweights were added to make the signal self-acting to the position of danger.

The left-hand arm when in a horizontal position indicated "danger" to an approaching train; the left-hand arm at an angle of 45° proceed with "caution;" and the arm altogether lowered "line clear." It now appears remarkable that this great improvement in signalling was not at once generally adopted. The old disc signals of various sorts still continued to be erected, and the introduction of the improved semaphore signal was comparatively slow.

On most British railways, the three signals "danger," "caution," and "clear" (Fig. 37), are still used at intermediate stations, and "stop" and "caution" at junctions. On some, as the Great Western, Brighton, Great Eastern, Metropolitan, and South-Western, only "stop" and "go on" (Fig. 38), and other companies seem inclined to adopt two signals only. This the Author conceives to be right, for wherever the block system is in use the "caution" signal means precisely the same as the "clear" signal, viz., "go on to the next signal-post;" and if not, then no amount of caution will afford sufficient security. There is another reason for the abolition of the caution signal, and the adoption of the 45° signal (or still better 60°, as on the Great Western), viz., when the arm is completely down, the signal is positively *absent*, thus in a measure reverting to the system (now found to be

insufficient) that absence of signal means safety. On the other hand, the horizontal arm for "stop" and the arm lowered 60° can always be seen. An arc of 60° is preferable to 45°, as it is less unfavourably influenced by variations in the length of the signal wires, caused by changes of temperature.

Now that so many arms are fixed on one post, or on posts near together, it is more than ever desirable that all signal arms should at all times be distinctly in view, so as to diminish the likelihood of one being mistaken for another.

A signal is said to be "on" when it is at danger, and "off" when at caution or clear.

Although distant signals were not generally used until long after the introduction of the semaphore, disc signals continued to be put up for distant signals, and the introduction of the semaphore was for a long time limited to the junction or station signals; and hence arose a special and limited use of the word "semaphore," as meaning "home signal"—a limited use of the word which continues to this day, even although all the signals may be of semaphore type.

Figs. 39, 40, represent the present ordinary semaphore signal, with lamp and glasses for night use. Sometimes the lamps are fitted with internal coloured glasses, movable either in a vertical or a revolving direction; but the usual plan is to have a fixed lamp, and movable external coloured spectacles. By using red and green lights only, if a coloured glass falls out the light is shown white, and thus a driver is able to warn a signalman of the defect; whereas, if red, green, and white are used, the falling out of a red glass would not be detected, because the driver would consider the light given as white (by reason of the failure of the coloured glass) as a genuine "clear" signal. Fig. 41 shows the light and elegant posts of Messrs. Stevens and Sons, of lattice iron; Fig. 42, the iron posts made by the Ribbon Post Company.

In fixing signals it is frequently necessary to make them very high, in order to obtain a sky background. On the North London, where the lines are much enclosed by houses, the signal-posts are sometimes upwards of 60 feet high, and it then becomes necessary to fix duplicate arms low down on the post. In Fig. 43, the high arm is seen against the sky from a distance; and as the driver approaches the post, and the high arm is less distinguishable, the lower arm becomes more so. The two arms, and of course the glasses of the lights also, are moved together by the same mechanism.

It is often convenient to put several arms relating to as many

roads on one post. For some time junction signals were frequently so arranged, but this has now been given up for the following reason:—In Fig. 44, if the signal-post planted in the fork carried all the four signals—up and down main, up and down branch—as the rule is for a driver to stop *at* a signal-post, one driver might come along the line x as far as the post, and in doing so have 'fouled' the branch line, when a train arriving from y would cut the first in two. This led to the plan of putting the down signals on one post in front of the switches, and the up signals in the fork (or *vice versâ*, as the case may be), and thus a driver arriving from the direction x would stop at the signal-post A, and one arriving from y would stop at the signal-post B.

A still better plan at junctions is to have a separate signal-post for each line.

Fig. 45 shows a case in which it is necessary in a station-yard to exhibit several signals on one post to provide for as many roads.

Until recently it was usual, though the practice was not universal, to put the main-line signal at the top, and then in rotation, the main platform, the goods, and the through crossing or other subordinate line.

Another plan is to make the top signal refer to the road farthest to the left hand, the next signal to the next road, and so on.

The first method has the advantage that the driver of an express train always knows that the top signal is the one for him, regardless of what station it may be, and of the arrangement of the lines. On the new plan the driver has to remember not only where he is, but also the arrangement of the roads at that place, and then he has to pick out his signal accordingly, which may be the first at one place, and the second, third, or fourth at others.

Another modification of several signals on one post is shown in dotted lines in Fig. 46, in which the signal farthest to the left hand also refers to the road farthest to the left. Although not long introduced, it is already found necessary to give some preferential distinction to the main line. This is done by making the main-line signal the highest, the platform signal the next, and so on. Thus a driver on the main line after all knows his signal not by its position with reference to the right or the left hand, but from its being the highest. There seems therefore to be no compensating advantage for the great amount of top weight and consequent instability incurred by the new arrangement.

The London and North-Western Company make the following distinctions of signal-blades, Fig. 47.

Top blade plain is for the main line.

Second blade, with an annular plate 15 inches diameter, fixed flat on the blade and near the end of it, is for the auxiliary line.

A blade with a plate in the form of an S refers to a siding.

On the Brighton railway, distant signal-blades are sometimes cut, Fig. 48, for the sake of distinction where signals are numerous.

Several companies paint the names of the different signals on the blades.

The semaphore signal is now rapidly superseding all other types of main and branch line signals, and will soon be universal as a means of guiding trains on their journey. The only other type likely to be of continued service is the disc, as a signal to trains which have to trespass on the main line in the course of shunting operations.

Figs. 49, 50, represent a ground indicator in general use; sometimes to show the position of switches for shunting purposes, but when worked by a separate lever in a locking frame, it forms a good signal for leaving a siding or for going through a cross-over road. The advantage of this signal for these purposes is that it is low down on the ground, and is usually seen only by the persons whom it concerns.

It consists of a lamp with red and green lenses and corresponding discs fixed on the lamp; the lamp is carried by an internal spindle having a short arm keyed on to it, and a rod or wire turns the lamp through an arc of 90°. Its normal position is with the red lens towards the siding, and the green lens being turned towards the siding by the signalman gives permission to come out of it.

Another disc for these purposes, on the Brighton line, is similar in construction and indication to that shown in Figs. 30, 31, excepting that one disc only is used 15 inches in diameter, and the post is only about 4 feet or 5 feet high.

A signal for leaving a siding (Fig. 51) has been lately designed by Mr. Blackall of the Great Western. It consists of a small semaphore arm, and a pair of red and white lenses fixed at an angle of 45°, so as to throw the light upwards. This signal can easily be made so as to be visible only from the siding and not from a distance on the main line.

Another useful purpose to which a small disc signal (Fig. 52) may be applied can be seen at the Victoria Station. The platforms are all furnished with departure signals of the semaphore type, and in addition to these there is a small disc signal appertaining to each platform, fitted on the opposite side of the

post. The discs are used to show that carriages standing there may be shunted across the main lines to the carriage sidings about $\frac{1}{4}$ mile off. These small discs (like the semaphores) are moved solely by levers in the locking apparatus, and can only be "given" after all necessary switches have been set to suit the operation about to be performed. The advantage of these discs for this purpose is, that each post already carries two semaphore arms relating to two platforms; and distinct signals being required for the carriage shunting, inasmuch as the carriage shunting crosses the main lines, the distinct type of signal has an advantage in being less likely to be mistaken.

Semaphore blades of a smaller size are sometimes used for the same purpose.

Distant Signals.

Signals placed at a distance in advance of the point of danger were first introduced in Scotland, after the opening of the junction of the Hawick branch with the main line from Edinburgh to Berwick in 1846. Two board signals, similar to Fig. 1, were erected, one for the protection of the up line, and the other for the down line. These were placed about 50 yards on either side of the pointsman's box, in front of which the switch handles were concentrated. The pointsman, having to walk to and fro to these signals many times in a day, arranged a wire, with a few chairs as a back balance-weight, so that he could from his box pull either signal to "safety." This was found to be such a convenience that a distance signal was put up at St. Margarets, near Edinburgh, 250 yards in advance of the point of danger; and after this distant signals became general. Their indications and working are just the same as the ordinary signals, with the simple difference that instead of being worked by a handle at the post, they are worked by a lever at a distance pulling on a wire to bring the signal to "safety" (Fig. 53), and a balance-weight and lever fixed on the post restore the signal to danger upon the wire being relaxed. If from any accident the wire should be broken the signal goes to the "stop" position.

The Great Northern railway was, at its construction in 1852, completely fitted with distant signals of the semaphore type, and this was, the Author believes, the first instance of the kind.

In practice distant signals are used in two ways:—

1. Where the distant signal is lowered first, and acts only as an

intermediate signal, the driver being expected to be prepared to pull up at the home or station signal. This is the practice at all stations on the Metropolitan, but not at junctions.

2. Where the distant signal is lowered only *after* the home signal has been set to "go on." In this case a driver finding a distant signal against him draws within it slowly, whistles to the signalman, and prepares to pull up at the home signal, if it should still be against him. If, on the other hand, the distant signal is at "go on," the driver expects to find the home or junction signal the same, and ordinarily does not pull up.

In order to secure completely this safe plan, it is desirable to have the distant and the home signals to interlock with each other, so that the distant signal cannot be given until after the home signal; for it has happened that a signalman has given the distant signal whilst the junction was still foul, expecting to get it clear before the arrival of the train, which the event showed he was not able to do.

Separate distant signals should also be fixed for each road, because, if not, there is nothing to show the driver whether the right road is prepared for him or not.

If only one distant signal be used, then it ought to be locked, so that it cannot be given if a branch road, goods road, or siding, is open; and for these the driver should creep within the distant signal until he could see the junction signals. The giving of a distant signal ought to imply a clear road for the main line; and if it be desired to indicate a clear road for the branch also, it can only be done satisfactorily by a *separate arm* on the distant signal post, as shown at *x*, in Fig. 44.

Sometimes when the signal is round a curve, or in a cutting, double distant signals are used; *e.g.*, one signal is fixed at about 1,000 yards, and one at about 400 yards. A driver finding the first one against him draws inside it, and goes at reduced speed to the second—by that time the second may be in his favour, but if not he draws very slowly within it. The second signal has also this advantage: the first may be out of sight of the signalman but the second in sight, and he can thus see that the signals are working properly.

Distant signals are sometimes fixed at 1,500 yards, but beyond 800 yards their action is always more or less uncertain, and should be checked by a repeater. Where the signal-post is round a curve, or is in any way obscured from view, such a repeater should also be fitted.

An electric repeater is a miniature arm beside the signalman,

controlled by an electro-magnet, the circuit of which is completed or interrupted by a contact maker fixed on the signal-post, and thus the movements of the signal are repeated on the miniature.

A mechanical repeater is a small disc or signal-arm beside the signal lever, worked by a return wire from the signal; thus, when the repeating disc or arm moves in consonance with the expectation of the operator, it shows that the distant signal has also been moved as intended. Mechanical repeaters are in use for all distant signals on the Metropolitan railway.

Where the distant signal of one signal-box is near the home signal of another signal-box, Fig. 146, a useful contrivance is the "slotted" signal, by which one signal does duty for both purposes. In Fig. 146 the same signal-blade C acts as home signal for signal-box A, and as distant for signal-box B. The rod R (Fig. 54) which actuates the signal has a slot in it, and is loaded by two weighted levers, the one being controlled by signalman A, and the other by B, either weight being sufficient to put the signal "on." Thus either man can keep the signal "on," but it requires the consent of both to take it "off." This signal is extensively used.

Stop signals are sometimes placed between a distant signal and a home signal of a busy station, to allow trains to stop under cover of them in readiness to enter the station as soon as opportunity offers.

Similarly, advance signals are placed a little beyond the exit of a station to allow the station to be cleared of departing trains. A train may go as far as the advance signal, and wait until informed by it that the line is clear to the next station.

Indicators.

The Author believes that the semaphore and disc signals are the only kinds likely to continue in use, but before the systematic introduction of locking apparatus several forms of switch indicator did good service; the type most used being Stevens's, Figs. 55, 56. It consisted of a signal-arm mounted in a V-shaped frame, actuated by a rod which received its motion from the switches. The blade laid to the right or left indicated which way the switches were standing. Below the arm was an arrangement of coloured glasses and lamp for night use. Various forms of lamp close to the ground have also been tried for showing the position of any particular set of switches.

The Great Western indicator is shown in Figs. 57, 58.

Deas and Rapier's post indicator in Figs. 59, 60. The signal-

blade and the spectacle-frame are united and hang on a pivot, the spectacle-frame being heavier than the blade. Upon a stud a short distance from the central pivot hangs a rod, and when the weight of this rod is on the stud it causes the blade to overbalance the spectacle-frame, and so brings the blade down and the glasses up to safety; the other end of this rod is connected to the balance-weight of the switches, so that an amount of movement not sufficient to be dangerous to the switches would yet lift the rod far enough to allow the signal to go fully to the "stop" position.

These indicators, as also the types shown in Figs. 61, 62, 63, are extensively used in Russia, Australia, South America, and other countries; but for crowded traffic they are altogether insufficient, and they are now superseded by more secure contrivances, to be hereafter described.

Self-acting Signals—Giving an Interval of Time.

During the last thirty years numerous inventions have been tried on railways, for the purpose of showing the length of time which had elapsed since the last train passed. Mr. Curtis on the Great Western, Mr. Gibson on the North-Eastern, Mr. Baronowski on the North London, have all made practical contributions in this direction. Mr. Baronowski's invention consisted of a mercurial column, which was filled by the motion of a lever (Fig. 64) actuated by the wheels of a passing train. The mercury passed freely into the column through a large valve in the piston, and dripped slowly out of it through a small aperture. The descent of the mercury in the column actuated a signal which could be seen by the driver of a passing train.

Self-acting Signals—Giving an Interval of Space.

Various attempts have also been made to render the signals of railways self-acting, so as to give an interval of space instead of, or in addition to, an interval of time.

Sometimes the small aperture in Baronowski's apparatus was controlled by a cock, which was opened by a wire actuated by means of the gear at the next signal station.

In 1864 Mr. Funnell made a series of signals (Fig. 65) for the Brighton railway. These were fixed between Brighton, Shoreham and Lancing. Their action was as follows:—Suppose an engine started from A, by means of a treadle it put the signal at A to danger. When the engine arrived at B it put a signal to danger at B, and the same motion by means of a contact spring completed

an electric circuit, which passed a current of electricity through an electro-magnet fixed at A, and thus released the A signal. Similarly when the train arrived at C, the C signal was put to danger and the B signal to safety. These signals were in use for some time, but were finally abandoned as the wires were constantly either purposely or accidentally broken.

On the North London, the Lancashire and Yorkshire, the Brighton, the South-Eastern, and other lines, a lever has been used for restoring signals to the "stop" position, by the wheels of a passing train. This arrangement sometimes did good service when the signals were worked by the porters of the stations, and they omitted to restore the signals to "stop" with sufficient promptitude. Now, however, these levers have all been taken out.

Another scheme has lately been brought forward for working the points and signals of a junction by levers which the engine-driver could present from the under side of the engine to gear fixed between the rails; but, supposing a perfect system of self-acting signals to be devised capable of working as a self-acting block system without the expense of a signalman, it would still be necessary to overlook each set every day to see that they were in proper working order. Again, such self-acting system would only be applicable to long stretches of road free from stations or junctions, because at stations and junctions there must be some intelligent control of the signals, their use at such places being of a character too varied to be reducible to an automatic mechanism. Such long stretches of road are so rarely to be found in this country, that it would not be worth while to introduce an exceptional system even if it were perfect.

Audible Signals.

Thus far visible signals only have been treated of; in foggy weather it is necessary to supplement the visible signals by a signal which shall appeal to the ear. In the year 1841 Mr. E. A. Cowper, M. Inst. C.E., designed the detonating fog-signal now universally used on the railways of this country. It consists of a thin metal case, 2 inches in diameter and $\frac{1}{2}$ inch deep, furnished with two leaden ears which can be readily bent down, so as to embrace the head of the rail, and prevent it falling off. (Fig. 66.) A small quantity of gunpowder is placed in the case, and is exploded by the compression of one or two matches as the wheel of the engine passes over the case. The matches are of the kind formerly called "Promethean matches;" they are made with

a small glass bulb of sulphuric acid inclosed in a little chlorate of potash and sugar, or other combustible wrapped in paper, and are very certain in their action. Recently, detonating powder has been substituted in some cases. In the first instance, Mr. C. H. Gregory, Past-President Inst. C.E., allowed trials to be made on the Croydon railway, where the efficiency of the new signal was so thoroughly demonstrated that it was adopted shortly afterwards. In the following year it was introduced on the London and Birmingham, and soon after on railways generally. Not only are all stations furnished with a supply, but guards, signalmen, and gangers are required to have constantly at hand a certain number of these fog-signals.

Each plate-layer has his appointed place at some signal-post, and being furnished with a supply of fog-signals, he uses them as follows:—Whenever a signal-arm is at stop he places a fog-signal on the line served by that signal; whenever the signal is put to safety he takes the fog-signal off the line again.

Contrivances have been proposed for putting fog-signals on the rail by mechanical means, so that, whenever a danger-signal was exhibited, a fog-signal should be presented to the rail. Other contrivances have also been proposed to signal to the driver by means of a bell or whistle on the engine without the use of a detonating signal. One system of this kind is in use on the Northern Railway of France, but it is substantially the same as that fixed in 1865 on the North British railway (Figs. 67 and 68), at the suggestion of Mr. John Anderson, Secretary of the Callander and Oban railway. On the engine, tender, or guard's van was fixed a gong, bell, or whistle, to be actuated by the movement of a lever hanging down from the under side of the engine or brake-van, this lever reached within a few inches of the ground, and its terminal end carried a pulley or roller.

When any signal was put to danger, a corresponding inclined plane, P, was slid into a central position between the rails, so that if an engine should pass it, the roller of the lever would touch the inclined plane, and the lever would thereby be elevated to the position shown in dotted lines, and the signal apparatus on the engine or brake-van put in motion. When the danger signal was taken off, the wedge-shaped block was slid laterally about 6 inches, so as to clear the lever hanging down from the engine. This apparatus was fully tested during eight months, when it was approved. Anderson's apparatus was also useful in case of repair of the line; the plate-layers being furnished with a wedge-shaped block of wood, had only to spike it to two sleepers $\frac{1}{2}$ mile in

advance, to ensure a driver receiving timely warning that repairs were going on.

Railway signalling has afforded many striking illustrations of the truism that "invention repeats itself;" and in the type of signal now under consideration this has been especially exemplified. Mr. Ager has, during the last three years, fixed several signals on the London, Chatham and Dover railway, the same as Mr. Anderson's except that, instead of sliding a solid inclined plane in a lateral direction to meet the depending lever from the engine, he adopts a steel spring about 6 feet long (Figs. 69, 70), mounted on a bar which turns on journals at each end, so that when the bar is caused to perform one quarter of a revolution the spring is laid flat, as shown in dotted lines in Fig. 70, and is thus taken out of the way of the gear on the engine. If an engine comes up when the signal is at danger, it would find the spring in the vertical direction, and the lever or rod (furnished with a roller) hanging down from the engine (Fig. 69) strikes the spring and thus receives motion sufficient to open the whistle on the engine.

The apparatus on the Northern railway of France is identical with Mr. Anderson's, with the exception that, instead of a lever under the engine, there is a metallic brush, which, coming in contact with the inclined plane, completes an electric circuit. This causes an electro-magnet on the engine to open a small steam-whistle which continues sounding until the driver stops it, thus arresting his attention—*provided* all goes well with the apparatus. If audible signals were adopted in addition to visible signals, there would be a tendency to cease to look out for visible signals, and too great dependence would be placed on the audible signals. A driver, so long as he heard no signal, would presume that all was in his favour. Now, quite apart from possible failures of the apparatus, this would be setting up the principle that absence of signal implies permission.

All plans of audible signals revert to the old idea of "*giving danger signals*," a system inadequate to the requirements of English railways.

Another form of audible signal, free from the objection above stated, has been contrived by Mr. R. Burn, jun. This is illustrated in Figs. 71, 72. If the signalman should deem it advisable to give an audible signal in addition to the ordinary signal, he moves an additional or supplementary lever (Fig. 71), which causes a catch to take into the ratchet-wheel carrying the signal wire, which is slackened sufficiently to allow the treadle to rise above rail level

and present an inclined plane to the lever or other gear fixed on the engine to receive the signal. This audible signal has the advantage of not always sounding the whistle as a matter of course when the semaphore is at danger.

Of Switches and their Connections.

In the early days of railways, switches consisted only of two pointed rails about a yard long, pivoted at the heel ends, and without any rods or gear. In entering facing switches, it was the duty of the fireman to descend and adjust the facing point, and as the wagons travelled slowly along, he, from time to time, gave the tongue a hitch to close it, in the interval between the passing of one wheel and another, an operation requiring both a quick eye for wheels and a quick hand at the switch tongue. The man who first fitted a pair of these primitive points with a rod and a lever was considered to have made an important invention.

When railways began to be constructed for passenger traffic, it was soon established that there should be as few "facing" switches as possible.

There is not so much danger with backing-out or trailing switches, for if accidentally left open to the siding, the flanges of the wheels of the engine and vehicles, pressing against the inside of the closed tongue, move it in the required direction.

The importance of the facing switch can be best appreciated by supposing a heavy mineral train travelling along a main line of railway (Fig. 44), and an express train being nearly due. It is desirable that the coal train should go into a siding and leave the main line clear for the fast train. Now this can be done either by means of a backing-out switch as at D, Fig. 44, or by means of a facing switch, as at F. To leave the line by the backing-out switch, the train, often a very long one, must go ahead its full length till the tail of the train clears the points. The train must then be brought to a stand, and next be put in motion again in a backward direction until the whole of the train is inside of the siding. It is obvious that this is an operation requiring much time, frequently ten minutes.

On the other hand, the "facing" switch allows the heavy train to clear the main line whilst it is still on the move, and without stopping until it is safely out of harm's way.

Now a main line of railway cannot be interfered with for ten minutes, unless protected by signal, and no protection by signal can be considered complete except by interlocking the switches with such signal.

Interlocking Apparatus.

As the number of junctions increased, it soon became apparent that not only must distinct signals be given for distinct lines, but that some kind of concerted action must be secured between signals and switches, as they might be conflicting. An important step was taken in this direction by Mr. Gregory, who, in 1843, at the Bricklayers' Arms Junction, gathered together chains from all the signals into a stirrup frame (Fig. 73); and a sort of parallel motion was fixed to the frame, between the stirrups, in such manner that the depression of any stirrup pushed the parallel motion so as to block one or more of the other stirrups, and thus it was impossible to give two signals which conflicted with one another at the same time. The switch levers were fixed on the same platform with the stirrup apparatus, but were not interlocked therewith. The switchman, while working the switches with his hands, worked the signals with his feet.

After this it was an easy step to make the switches lock also. The first idea was to couple together any set of switches with its own proper signal, so that the signals and points should move together *pari passu*. This soon appeared to be insufficient, because sometimes the signal moved and the points did not, or *vice versâ*, and thus it was found that the mere *connection* of signals and switches did not fully meet the case. Switches and signals are said to be *connected* when they are simply coupled together and have a *pari passu* motion; they are said to be interlocked when the movement of a signal to safety cannot be *commenced* until after the necessary movement of the switches has been *completed*, and also the movement of switches cannot be commenced until after all the signals concerned by them have first been set *fully* to danger.

The first interlocking of switches and signals took place at East Retford Junction, in the year 1852. Though the contrivance was simple in the extreme, it contained the germ which has developed into the systems of interlocking now in use.

A signal had been given for a train to start whilst a pair of facing points in front of the train were still open. As the points happened to be close to the signal-post, a flat bar was brought from the near switch tongue close past the foot of the post (Fig. 74), and the vertical rod which moved the signal was continued down the post to meet the flat bar. The flat bar travelled with the switches, and when the latter were in the right position for the

main line, a hole in the bar opposite the signal-rod allowed it to pass through, and the signal could be set to safety. After the signal was lowered, the points could not be altered, because the signal-rod passing through the bar, as shown by the dotted lines, prevented any alteration of its position. If the points were in the opposite direction, the solid part of the bar was opposite the signal-rod, and the signal could not be moved.

This simple kind of locking has been extensively used as a signal-post lock, and in the form known as the goose-neck lock (Figs. 75, 76), and the notch lock (Fig. 77, 78).

The wire which moves the signal has interposed in it a square bar, with a long pointed piece forged on and parallel to it, in such manner that the square part moves in guides, and the round limb parallel to it comes opposite to a prolongation of the switch rod, which also moves in guides. A hole is made in the prolonged switch rod so that, when the switches are in their right position, the bolt of the goose neck can pass through, and the wire be pulled and the signal given; but with the switches in a wrong position, the solid part of the rod is opposite to the point of the goose-neck bolt, and prevents the signal-wire being pulled. Similarly, when a signal has been given, the bolt of the goose neck passing through the switch-rod prevents the switches being moved until after the signal is restored to danger and the goose-neck bolt thereby withdrawn. Sometimes the same signal-wire is coupled to goose-neck locks appertaining to several sets of switches concerned by that signal.

The more complete development of the interlocking system, by the use of apparatus, in which all the movements of switches and signals are rendered harmonious, is illustrated in Fig. 44. This is a ground plan of an ordinary double junction, and for its working nine levers are required, viz.:—

Up switch lever.
Down switch lever.
Up main distant signal.
Up main junction signal.
Up branch distant signal.
Up branch junction signal.
Down main junction signal.
Down branch junction signal.
Down distant signal.

Instead, however, of having only one down distant signal, it is better to have a down main distant and a down branch distant,

thus increasing the number to ten levers, and if a lock-lever be added for the facing points, to eleven levers.

The switches are coupled to their respective levers by rods working in guiding rollers, mounted in small cast-iron frames. Sometimes these frames are made with a lid for protection from the weather (Figs. 79, 80). The rods are usually gas pipe of 1 inch internal diameter. If the lengths are joined by screwing, a solid plug should be inserted and riveted into each end of the tubes as an extra safeguard. When the switch-rods exceed 30 yards long, an expansion lever (Fig. 81) should be placed midway between the switches and the signal-house, and then any expansion of the rods in one direction is compensated by the like expansion in the other —without such levers the varying length of the rods prevents the correct working of the switches. The levers, bell-cranks, pedestals, and screw couplings should all be made of wrought iron. The signals are coupled to their respective levers by similar connections of ½-inch gas pipe for short distances, and by wires for long distances. The greatest distance at which switches are so coupled is 410 yards on the Great Western at Moulsford, but this distance is found to be excessive for traffic, though not for mechanical, reasons. Signals are worked at distances of 1,400 to 1,500 yards, but any distance beyond 800 yards is troublesome.

Besides the signals and switches of junctions—level crossing gates, canal bridges, and even turntables are sometimes interlocked; in short, whenever any one operation interferes with the performing of another, the interlocking system ought to be applied.

The normal position of switches at a junction should be as in Fig. 44, so that the points are open to the outermost roads respectively. Thus a down train accidentally overrunning the points would go along the branch, and would not run foul of a train which might be coming along the up branch line.

The principle of all interlocking systems is, that the signals can only be given in harmony with the setting of the switches, and *vice versâ*. For example, suppose an up branch train is expected, the up switches must first be set for the branch, and this movement of the switch lever ought to lock the up main signals and the down main signals, and unlock the branch up signals: the branch up home signal should then be lowered or "given," and then the up branch distant.

Much on the same plan as Mr. Gregory's concerted signal frame, Mr. Chambers, some years later, extended the locking (previously confined to signals only) to the switches, but not to the distant

signals. A frame on this plan, believed to be the first of the kind, was put up at Willesden Junction in 1859.

The frame was built by Messrs. Stevens and Sons; the interlocking was suggested by Colonel Yolland, and a race ensued between Mr. Chambers and Messrs. Stevens to prepare the necessary fittings.

Figs. 83 to 87 show Mr. Chambers' junction apparatus.

The up switches actuated by the lever U are open to the main line.

The down switches actuated by the lever D are open to the branch line. The upper stopping plate U works with the up switch lever. The lower stopping plate D works with the down switch lever.

When the up points are open to the main line as in Fig. 44, the up main signal can be given, because in that position of the plate U, there is a hole in the plate opposite the leg of the stirrup, which allows it to pass through. But the up branch signal could not be given, because there is no hole in the plate U opposite the leg of the stirrup which moves the up branch signal. Also as long as the up main stirrup is pressed down to give the signal, the up points U cannot be altered, because the leg of the stirrup locks the plate U.

But suppose the stirrup allowed to go up to danger, then the lever U can be brought over to open the up points to the branch line; and, in so doing, the plate U is thrust forward, so that its solid part comes under the up main stirrup, which is thereby locked; but the part under the up-branch stirrup now has the hole under the up branch stirrup, which is able to pass through.

By thus providing all switch levers with plates passing under the signal stirrups which concern them, making holes in the plates so as to allow the signals to be free, and no holes where the signals ought to be stopped, the complete interlocking of switches and signals was obtained.

In another variety of Mr. Chambers' apparatus, Fig. 86, a handle was used for signals with a prong bent in the arc of a circle, which prong was locked by the switch plates in the same way as the stirrups before described.

This arrangement was efficient so long as any signal had to be locked by only one or two sets of switches, but if a signal had to interlock with several sets of switches, say for example, ten or twelve, as in Figs. 86, 87, and that the first ten happened to be free to the signal, and the last one not free, a considerable movement of the signal might take place before it was checked by the last plate.

The switches and signals are now all worked by levers arranged in a row; and the levers are usually sorted, so as to have the signal levers at the ends of the frame, and the switch levers at the centre. Sometimes the switch levers are arranged adjacent to the signal levers to which they relate; and, in a long frame, this plan is more convenient to the operator, as all the signal and switch levers which have to be moved for any one operation are close together. Fig. 115 is an example of this arrangement, being a drawing taken from a photograph of a frame of eighty levers, made for the level crossing of the Great Northern with the Manchester, Sheffield, and Lincolnshire railway at Lincoln Station. It will be observed that in this frame there are no less than twelve directions for the arrival and departure of trains, and that in each case the levers required for any one train are close together.

At the Waterloo Station Messrs. Stevens and Sons arranged the levers in two rows, and lately, at the new City Station of the Great Eastern railway, Messrs. McKenzie, Clunes, and Holland have arranged them in four parts.

Shortly after the completion of Mr. Chambers' apparatus a great step was made by Messrs. Stevens and Sons. Horizontal bars having hooks or claws on them, Figs. 88 and 89, were arranged in guides, so that the hooks engaged on to the levers. A spiral spring pressed the bars to the left, and they were moved to the right by the pressure of the lever against a short inclined piece mounted on the bar. In the normal position, Fig. 88, the bars are thus kept to the right and the hooks lock some of the levers. When any lever is moved into the secondary position, as soon as the pressure of the lever is withdrawn, Fig. 89, the spiral spring pushes its bar into the secondary position, and so unlocks the levers which were locked, and locks those that were unlocked. The back-locking of the switch levers by their respective signal levers was performed by subsidiary catches fixed on the levers, about halfway down their length.

In Messrs. Saxby and Farmer's apparatus, Figs. 90, 91, and 92, the switch and signal levers are arranged in a row, and have about half their length above, and the other half below, the floor of the signal-house. Under the floor are, in a horizontal plane, short locking levers between the switch and signal levers, each locking lever moving on a pivot p at the inner end, the outer end being articulated to a locking bar b, moving in guides, and having locks, L, L, L, attached to it in positions corresponding with the requirements of the various levers. The edges of the

active locking levers are slanted cam fashion, so that when the motion of the switch lever comes in contact with the locking lever the latter was operated sufficiently to cause the passive locks L, L, Fig. 91, to engage the levers C, D, but not sufficiently to unlock the lever X. The middle part of the movement of the switch lever does not affect the locking lever, but the latter part completes the movement of the locking lever, thus still further securing the levers C, D, by the locks, and releasing the locks of the lever X, Fig. 92.

If, for example, a main-line signal be given, by the lever X being drawn over, this movement of the lever backlocks or secures the switch lever A in the right position for the main line. Of course any one lever may require to be locked by any one or more other levers; this is done by successive tiers of locking levers, similar to the one tier shown in the figures.

Many varieties of similar apparatus were subsequently designed, the general principle of all being, that locking bars moved in *horizontal* planes should interlock the levers moving in *vertical* planes; the chief point of difference being the method of causing the levers to impart the necessary motion to the locking bars.

One of these, made for the late Mr. Michael Lane, M. Inst. C.E., is shown in Figs. 93, 94, and 95. The necessary motion was obtained by a rack attached to the switch lever, which caused a pinion to revolve. This pinion was fixed on the axis of a screw, which being thereby made to revolve in a fixed nut, travelled in a horizontal direction, thus obtaining the necessary change of position of the locking bars or plates. This method was not so good as those before described, as the locking was obtained only by what may be called a *pari passu* motion, whereas the other plans secured the locks comparatively earlier in the stroke of the lever and released them comparatively later.

Messrs. Skinner, Baines, I'Anson, and others, likewise produced different modifications.

Another kind, Fig. 96, made by Mr. Francis Brady, M. Inst. C.E., was of a stronger construction and less likely to be deranged by the application of excessive exertion at the handle. The switch and signal levers are in a row. Under the floor horizontal shafts appertain to, and are actuated by, the different switch levers; on these shafts are fixed cam pieces opposite to such signal levers as are concerned by those switches; from each signal lever a pair of long connecting links proceed in a direction at right angles to the shafts, and articulated to these links are concave arms moving on pivots fixed on the bed plate. The concave arms worked by the signal

levers are opposite the cams which are worked by the switch levers in such manner that any signal lever can only be moved when all the switch cams are turned away from the concave arms worked by that signal lever. If any switch cam be turned towards any signal concave arm as at B, that signal lever is thereby locked. Also, when any signal lever has been moved, the concave arms fit against the cams on the shaft worked by the switch levers, as shown by the black dotted lines at A, Fig. 96, and so prevent the latter from being altered. This apparatus is extensively used on the South-Eastern railway. It consists of many parts, but it is strong, and the various parts are fac-similes of each other.

A decidedly different apparatus was brought out by Messrs. Livesey and Edwards (Fig. 97). Above each lever was a short arm mounted on a pivot at one end, and finished at the other end in the form of an eyelet. The short arms were actuated so that when any handle was moved which required the locking of the signal lever A for example, the mechanism pulled down the short arm so that the eyelet embraced the end of the signal lever and securely locked it. This method had the great advantage that the locking was all in sight: but it had the great disadvantage of requiring another plan of back locking, *i.e.*, securing the switch lever in its new position by the subsequent movement of the signal lever.

After the various locking apparatus above described had been in use a few years, and the wear and tear of actual working began to have its effect, two points arose requiring attention—

1st. The locks, with the exception of Mr. Livesey's, had hitherto been all under the floor, and so far down the length of the lever, that the signalman had considerable leverage over them and the pins and studs on which they were pivoted, and as a good deal of force was often applied, it frequently happened that some part of the apparatus was damaged.

2ndly. Wear and tear resulted in considerable clearance between the locks and the levers, so that levers were frequently imperfectly locked.

Recent Interlocking Apparatus.

The next decided step was to perform the locking and interlocking by means of the spring catch rods used for securing the levers in their places.

Figs. 98 and 99 show Mr. Easterbrook's method of effecting this. Each catch rod has a prolongation extending some distance below the floor. On the outer side of this rod are notches $\frac{1}{2}$ inch wide,

and 1 inch pitch. Adjacent to these, horizontal bars, also notched, are so placed in guides that the teeth of the bars engage into the teeth of the catch rods to prevent their movement. When the bars are slid along so that a notch comes opposite to a catch rod, then that rod can be moved.

The horizontal bars have motion imparted to them by the catch handle of the lever to which they belong. This movement is imparted simply enough when the levers are in their vertical position; but in order to obtain it after the lever has been moved into its new position, Fig. 99, a sector lever has to be provided, so as to permit of the catch rod travelling along the sector. When the transit of the lever is completed, the depression of the catch rod depresses the sector lever, which in its turn moves the sliding bar into its new position.

This method of locking has the advantage that the man's hand has not much leverage over the locks, and so cannot strain them; and also the advantage that the locking of the signal levers that ought to be locked is completed before the switch lever begins to move, and the unlocking is not accomplished until after the movement of the switches has been fully completed. The complication, however, is great, and the number of pieces in the gear considerable.

Similar apparatus was made by Messrs. Saxby and Farmer. Recently, however, a much improved machine has been produced by that firm, Figs. 100 and 101.

The levers are arranged in a row as usual, and 6 inches apart. Between the levers are sector plates mounted on pivots 6 inches above the floor. Each catch rod terminates in a substantial end piece, which carries a stud projecting laterally so as to engage the slot of the sector. When the lever is in its forward position, the catch rod depresses the sector into the position shown in black line. On the top of the sector, and formed in the same piece with it, is a lever rising perpendicularly for 16 inches, and terminating in an eye; coupled to this eye is a locking bar, which is thrust out in a horizontal and forward direction. Now it will be seen, that if the handle be pressed against the lever, the catch rod will be elevated and with it the sector, thus causing a movement of the eye of the sector lever, and consequently a movement of the locking bar. In this position of the sector the arc of the slot is true to the pivot on which the lever moves: consequently as the lever is drawn over no movement of the sector takes place. When the movement of the lever is completed, the depression of the catch rod and stud depresses the sector, and the sector lever draws the locking bar still farther out. Each signal lever has

a locking bar with notches cut in it, moving in a to-and-fro direction.

In the frame in the rear of the levers are arranged bars moving in a longitudinal direction, and each switch lever has one of these longitudinal bars belonging to it. These longitudinal bars are so near to the transverse locking bars of the signal levers, that locking pieces mounted on the switch bars may engage into the notches of the signal bars. Given the signal bar with as many notches in it as there are switch bars, it is clear that locking pieces may be mounted on any switch bar so as to lock any signal bar in any desired manner.

The switch levers have also sectors, but their thrusting bars, instead of being notched, are furnished with a male wedge piece, Fig. 101, engaging into a dove-tailed wedge piece fixed on the longitudinal bar belonging to that set of switches, so that the reciprocating motion of the bar in a to-and-fro direction draws the longitudinal bar in a longitudinal direction. For economy of space some of the longitudinal bars are placed above, and some below, the transverse bars, as shown in Fig. 100.

If it be proposed to move any signal lever, the depression of the catch handle at once shows whether the signal lever is locked or not. If it be not locked, the depression of the catch handle draws out the locking bar $\frac{1}{2}$ inch and thus opposes the solid parts of the bar to the locks on the switch bars, and consequently no contradictory switch could be moved.

This apparatus is so strong in principle, that it is made almost entirely of cast iron, and all similar parts are cast from the same patterns.

In Messrs. Stevens and Sons' new frame, each lever has one or more thrusting bars attached to it. These thrusting bars pass through guiding bars fixed in the frame, and running in a longitudinal direction. Between the guiding bars there are sliding blocks which abut against one or other of the thrusting bars of any two conflicting levers, Figs. 102, 103.

If lever No. 7 be moved, the bar *a* would thrust the block *b* against the thrusting bar of lever No. 8, which would be thereby locked.

If any lever (say No. 5) has to lock a lever, No. 7, at a distance from it, their respective sliding blocks are connected by links L, L, shown in dotted lines. When the levers are well sorted, so as to lock adjacent ones, comparatively few of these links are required.

A new locking frame is also made by Messrs. McKenzie, Clunes,

and Holland, of which there is a good example at the new Liverpool Street Station of the Great Eastern railway.

In Mr. Poole's gear the usual detents and spring catch handles for securing the levers in position are dispensed with, and the levers are pressed by springs into recessed notches in the top plate of the apparatus. Before the operator can pull any handle towards him, he must first move it in a lateral direction to get it out of the notch, and this preliminary movement performs the locking. It will be seen from Fig. 104, that if the switch lever be pressed laterally so as to release it from the notch, the lower part of the lever (Fig. 105) will move the sliding bar to the right, and this, by means of the bell-cranks, the locks L, L, so that their projections will come in front of the levers for the main home and main distant signals and prevent those levers being moved laterally out of the notches in the upper catch plate. There are also detents for preventing the sliding bars being accidentally disturbed, but the above is the principle of the locking. Each switch lever and each distant signal lever requires a set of locks, and the successive sets are arranged in tiers.

Mr. Buck's apparatus is on the principle of having one substantial lock to each lever mounted on pivots formed as a continuation of one edge of the lock, Fig. 107, so that when left to itself the lock falls clear of the lever, Fig. 106; part of the axis of the lock is square, and from the vertical side of this square a plate P hangs vertically. This plate is for the purpose of extending over several longitudinal sliding bars A, B, &c., Fig. 108, running the whole length of the frame. These sliding bars are appropriated to and actuated by such switch levers or signal levers as require them; and on them brackets are fixed (Fig. 106) to engage the vertical plate of any lock, or locks, which it may be desired to move into the locked position.

When a lever is required to interlock with several others, it is fixed only once by its one lock; but this can be moved by any of the levers concerned, and any number of successive levers being moved do not interpose successive locks, but they simply lock a lever, if this is not already effected.

An examination of the various complications of locking apparatus led the Author to consider whether some simpler construction could not be devised, for there are thousands of parts in a single machine.

In attempting simplification, the Author determined to disregard all previous systems, and to commence, as it were, *de novo*. The subject was successfully reasoned out as follows: As a first

principle it may be predicated, that it is quite easy to lock a number of levers in their normal position by shooting bolts through them, or over them, as in Messrs. Stevens's first apparatus. When, however, any lever is moved into its secondary position, it can no longer be locked or unlocked by the same bolts, because the lever has moved away and is no longer near the said bolts; therefore the locking and unlocking in the secondary position must be accomplished by other locking bolts or bars. The Author conceived the idea of making each lever with a sector forged on it (Figs. 109, 110), so arranged that there should always be some part or other of the sector adjacent to all the locking bars, and thus the same locking bars could perform both the primary locking and the "backlocking." In this he succeeded so well as to lock and backlock all the levers of a ten-lever junction, by means of only six moving pieces, and the whole of the levers of an eighty-lever frame (Fig. 115), for the Great Northern railway, by only twenty-seven moving pieces.

In Fig. 110, lever No. 3 actuates the down points. As the frame stands, the down points have just been opened to the main line, and the locking bar X has been moved to the left, and is in the position shown in Fig. 111.

The sectors have notches cut in them wherever the locking bars ought to pass through, and are left solid where the bars ought not to pass. X is the locking bar belonging to lever No. 3, and Y to another switch lever. These bars are moved by flanges forged on the sectors, working in finger pieces fixed to the bars, Fig. 114.

The bars are shown in plan with the levers in section, Fig. 111, 112, and 113. It will be seen that when lever No. 3 is down the main-line signals are movable, and the branch-line signals are locked. If the switch lever, No. 3, be put up so as to set the switches in favour of the branch, the first part of the motion causes the flange of the sector to move the locking bar into the position shown in Fig. 112, by which it will be seen that all signals are locked, and after the motion of the lever is completed the bar is put into the position Fig 113, thus still farther locking the main-line signals and unlocking only the branch-line signals. Now if a branch-line signal, No. 2, be given, the solid part of the sector of No. 2 comes into the notch in the bar, and thus renders its motion impossible, and by consequence the switch lever to which it belongs, so long as the signal is given. To move any switch lever it is necessary that all the signal levers which concern it be restored to danger or stop.

The possibility of thus making a locking apparatus being thus established, the next inquiry should be as to its efficiency.

1st, as to locking early in the travel of the lever; the amount of movement required to effectually lock all levers is only $\frac{1}{2}$ inch at the man's hand, and $\frac{1}{16}$th inch at the short end of the lever to which the switches are connected, an amount far less than the slack or spring of the gear; and thus the locking is secured before the switches begin to move.

2nd, as to strength of the locking mechanism; this is satisfactory, inasmuch as the locking is obtained simply by the interlocking of two notched bars, without the intervention of pins or articulated parts; these bars are $\frac{1}{2}$ inch thick, and the man's hand has only a leverage of 2 to 1 over them, an amount quite insufficient to enable him to injure either of them.

3rd, wear and tear may reasonably be taken as diminished in proportion to the diminished number of pieces, and further by the circumstance of their being almost all of wrought iron and machine cut.

4th, all the apparatus is in sight, and can be readily examined or taken out for any necessary additions or alterations.

The majority of engineers shrink from the effort to follow the complex arrangements of a large locking machine. The apparatus under notice demonstrates that complete interlocking can be accomplished without any complexity of parts. The whole of the switch levers and distant-signal levers are interlocked by the addition of only one moving piece to each lever, and all other signal levers are interlocked without any additional parts whatever, simply by making the levers themselves of the right shape.

Level crossings.—A detail, which appears to have some advantage in dealing with level crossings, is to have a separate locking bar or lever so that in one position all the signals of one road are entirely locked, and in the other position all the signals of the other road are locked. This plan has the advantage of giving the operator something special to do, in such exceptional cases, as changing his attention from one line to another which crosses it. In Fig. 115 is shown a locking-up bar worked by a lever for determining which railway is open and which is locked. When the lever is in its normal position the Great Northern line is free and the Manchester, Sheffield, and Lincolnshire line is locked. If the lever be brought down the locking-up bar would be slid to the left and the Great Northern signals would be locked, and the Manchester, Sheffield, and Lincolnshire signals would be free. This plan is also adopted for locking canal bridges, turn-tables

street gates, &c., which are all level crossings of less degree, but similar in character to the crossing of one railway by another.

Switch Locks.

From the confidence engendered by the interlocking system a new danger soon arose.

It frequently happened that a signalman reversed the switches before the whole of the train had passed over them, and thus caused part of the train to change lines, or to go off the line altogether. In 1867 Messrs. Livesey and Edwards made a switch lock to prevent this sort of accident. It consisted of a bar 12 feet long laid close to the rail, either inside or outside, and articulated on fulcra somewhat after the fashion of a parallel ruler (Figs. 116, 117). In the completed position of the switches either way, this bar lies so that its upper surface is just below the wheels. In order to produce any movement of the switches, the bar must be elevated; and the bar cannot be elevated if any wheel of a vehicle is resting upon it (Fig. 118). At first this bar was actuated by the same lever which moved the switches; but in 1869 Messrs. Saxby and Farmer made the important improvement of actuating this lock by a separate lever. This has been further improved by the addition of a locking bolt acting upon a bar connected with the switches in such a way, that if the switches were not fully home to one side or the other, the bolt would not enter either of the holes provided for that purpose (Figs. 119 and 120).

On this plan any set of facing switches is controlled by two levers in the locking frame. If it be desired to move a particular set of switches, the lever which locks them must first be drawn over so as to withdraw the bolt. As this lever acts at the same time on the long bar, the locking bar cannot be lifted if any portion of a train is still passing over it, and consequently in that case the switches could not even be unlocked, much less moved. After the switches are unlocked, their position can be changed, and then the locking lever must be restored to its place before a signal can be given, for the signals are interlocked by the locking lever so that no signal can be given, whilst the locking lever is in the unlocked position, and when it is in the locked position signals can only be given in accordance with the position of the switch lever.

This invention provides against the most dangerous class of accident. The locking bolt ascertains whether the switches are fully set in one position or the other, but not if the switches have moved, or remained stationary. For example, the rod leading

from the signal box to the switches might be broken, and the locking bolt would not in the ordinary course ascertain the fact, because it locks up just the same for either completed position of the points.

In some switch-locks now being manufactured for the Great Northern railway, the Author has supplied this desideratum.

Fig. 121 shows the position of the locking bolt when the points are locked for the main line; Fig. 123 when locked for branch line; and Fig. 122 when unlocked. The switch *bar* has a T-shaped aperture, Fig. 121. The locking bolt has one end $4\frac{1}{2}$ inches broad on the horizontal line and 1 inch thick, the middle part is 1 inch square, and the other end is 3 inches broad on the vertical line and 1 inch thick. Now in the mid-position of the lever, the lock, Fig. 122, is in mid-position also, and the switches can be moved either way. If the switches be moved in favour of the branch, then the locking lever can only be got home by bringing it down in favour of the branch also, and *vice versâ*, because the horizontal limb would not enter the vertical hole. This plan ascertains whether the switches have moved in the direction intended or not. It covers the contingency of the fracture of the rod which ought to move the switches; for if a signalman found that the lock lever would not come home in favour of the branch, he would be thereby informed that the switches were not home for the branch, and, of course, all the signals would remain locked.

Varieties of the locking bar, but without the lock-up lever, have been made by Mr. Brady, of the South-Eastern railway, Fig. 124; Mr. Buck, of the Brighton railway, Fig. 125; Messrs. Stevens and Sons; Mr. Bell, of the North British railway; and Mr. Luke, of the Great Western railway. All these are similar in principle, and differ only in detail.

Messrs. Stevens and Sons' switch lock consists of a long bar in advance of the switch, like a movable checkrail. In its normal position a balance-weight causes it to touch the running edge of the main rail (Fig. 127). This bar is moved away from the running edge by the gear which lowers either signal, by means of the cranks *c* or *d* engaging into the slotted bar *b*; at the same time a goose-neck bolt (Fig. 128) is shot into the switch rod *r*, taking into the hole provided for the main line or the branch line according as the points may be set. Thus as long as the lock-bar is open the switches are locked, and the bar cannot be shut as long as any vehicles are passing because the flanges of the wheels are interposed between the bar and the rail.

The use of the slotted bar *b* enables the signalman to restore

the signal to "stop" before the train has fully entered the points; in that case the bar is simply kept open by the flanges of the wheels, and after they have all passed it is closed by the balance-weight and chain P. This gear is complete, with the exception that it does not discover whether the switches have moved in the direction intended or not; the goose neck locks up the same way both for main line and branch.

Mr. James Bell Junr.'s switch lock has a bar like Messrs. Stevens's, but coupled to and working with the switches, and the main and branch signal wires are locked with the switches on a similar plan; except that the locks are so arranged that only the right signal can be given, corresponding with the actual position of the points, and an erroneous position *would* be discovered.

The varied movements of the switch locking bar in a vertical direction by Messrs. Livesey and Edwards, in a lateral direction by Messrs. Stevens and by Mr. Bell, in an arc by Mr. Buck and by Mr. Brady, are further supplemented by Mr. Luke of the signal department of the Great Western railway. Mr. Luke moves the bar in a longitudinal direction. It is placed (Fig. 126) just so that the flanges of the wheels touch it, and as it were tend to kick it away in the contrary direction to that in which the train is moving. In order to unlock the points, the bar has to be moved in the same direction as the train is travelling, which cannot be done whilst the flanges of the wheels are tending to push it the other way.

Another type of switch lock has been introduced by Mr. Harrison, President, on the North-Eastern system of railways. This lock has for its principal object the securing of the switch tongues *at* the point by means of iron wedges, which are pushed home by the apparatus after the movement of the switches has been completed (vide Figs. 129, 130 and 131). The tongues are actuated by a plate with a cam-shaped groove in it (Fig. 130), and moving in guides; at the first part of the motion it will be seen that no movement of the tongues takes place whilst the straight part of the groove is passing the actuating stud, but during that part of the travel the wedges are withdrawn; then the angular part of the groove presses against the stud and moves the tongues, and finally during the travel of the remaining straight part, the wedges are slid into place again to hold the tongues in the contrary position, the closed tongue being held tightly against the stockrail, and the open tongue being also secured by being held in a slot formed in the body of the wedge for that purpose, Fig. 130.

The switches are thus well secured against accidental displace-

ment by the train itself; they are also secured against being inadvertently moved by the signalman, by the addition of any of the long locking bars above described.

In a lock for securing switches at the extreme point by Messrs. McKenzie, Clunes, and Holland, Fig. 132, the locks L and M are moved by the same mechanism as the signals of their respective roads. When both signals are at danger, both tongues are unlocked. Now if it be desired to give a signal for a train to go along the main line, the same gear which moves the signal also pulls the lock L into the position shown in the figure, and this lock presses the tongue close to the stockrail. If any attempt were made to move the branch-line signal, its lock M would strike against the end of the open tongue, and the signalman would thus be informed that the switches were not in favour of the branch.

These locks prevent the switches being moved until after the signals have been restored to "stop," but they do not prevent the switches being disturbed whilst a train is passing if the signals have been quickly restored to the stop position.

Mr. Price Williams's switches, Figs. 133 to 136, are intended to give a continuous road, and are in course of trial at Crewe.

Another kind of apparatus for a similar purpose, but specially adapted for India, was made by Mr. John Brunton, M. Inst. C.E. (Figs. 137, 138, 139, 140, 141.) The first part of the motion of the handle A turns "on" a signal disc (Fig. 138), and at the same time elevates the tongue rail of the switch, which cannot be done with a train on (Figs. 139, 140). The further motion of the handle causes the tongues to move laterally into their other position, by means of the worm on the revolving shaft acting on the rollers fixed on the switch rod. The concluding part of the motion allows the closed tongue to descend, and to become locked by the block locks, and also reverses the signal arrow, which always points to the side on which the road is open (Fig. 137).

The principal object Mr. Brunton had in view was the provision of mechanism, adapted for manipulation by native pointsmen. Hence the desire to accomplish the several operations of moving the switch, locking the switch, and showing the signal by means of one handle only. After preliminary trials in England and Scotland, two sets of this apparatus were made for the Great Indian Peninsula railway, and sent to Bombay, but there has not been time yet to have news of their performance in working. For India and similar countries, where the places to be protected are chiefly the entrances from the single line of way to the

stations, Mr. Brunton's apparatus has the advantage of being less costly than a complete locking frame, and perhaps better adapted for native use.

Having thus shown that facing switches may, by the use of proper appliances, be rendered as safe as backing-out switches, the Author will now proceed to describe some of the conveniences of facing switches—conveniences which cannot be had without their use. This is perhaps the most suitable place to refer to the circumstance, that, for many years, facing switches were used on the London and North-Western line, about a mile out of Euston Station, for receiving an assistant locomotive from the front of the train. Heavy trains leaving Euston require two engines to get them up the steep gradient to Camden. After the train was well started, the front engine was disengaged by a slip coupling, and then ran on a few yards in front of the train. A pointsman, standing all ready, opened the switches to receive the first engine into the siding, and immediately reversed them to allow the second engine and train to proceed on the main line. These points were not worked from a signal box, which would have been unsafe, but by a man on the ground. The distance was too short to cover the operation by signal of any kind, and it was entirely a matter of careful handling. These points were so used for fifteen years, many times every day, without any accident occurring. Their use was discontinued five years ago, when the train arrangements were changed, so as to allow all trains to stop at Willesden. Since then the auxiliary engines have been unhooked at Willesden. This is a remarkable testimony that facing points, well looked after, are not necessarily dangerous.

Facilities now afforded for getting the Fast Traffic Clear of the Slow Traffic by means of Facing Switches.

The absolute block system enables the greatest possible number of trains to travel over one pair of rails in a given time, and the various contrivances of complete signals, interlocking apparatus, and facing switch locks tend to insure the safety of the traffic—indeed without all these mechanical adjuncts it would be impossible to work the block system satisfactorily.

Already the numbers of trains on several railways are far beyond what would be possible without the block system. For instance, on the North London railway, at Liverpool Street, 250 trains pass over the same rails in a day of nineteen hours, giving an average of only four minutes between the trains, and fre-

quently the interval is only two minutes. Without the certainty afforded by the block system that that interval of time represented a real interval of controlled space, it would be far too short.

On the Metropolitan railway 193 trains per day traverse the same metals, and 400 trains could with safety be passed, inasmuch as 20 of them pass in one hour; but here the trains all travel at the same speed. On the North London railway nearly the same conditions obtain as on the Metropolitan, as to identity of speed of the trains following each other.

The Metropolitan railway between King's Cross and Moorgate Street is laid with four lines of rails, two lines being reserved for the use of

The Metropolitan,
The Metropolitan District, and
The Great Western Companies,

and the other two lines called the "Widened lines" being set apart for the traffic of

The Midland,
The Great Northern, and
The London, Chatham, and Dover Companies.

The following extracts from the Company's working Time Tables, show the intervals at which the trains run during the busy period of the day, viz., 9·0 to 10·0 A.M.

EXTRACT No. 1.—MAIN LINE.

NOTE.	Description.	Arrive at Moorgate Street.
		A.M.
	G. W. and D. K.	9·0
G. W. and D. K. signifies joint Great Western and District trains.	D.	9·5
	H.	9·10
	D.	9·15
	H.	9·20
D. signifies District.	D.	9·25
	G. W. and D. K.	9·30
	D.	9·35
Metropolitan Co.'s trains. H. signifies Hammersmith. M. „ Main line.	G. W. P.	9·38
	H.	9·41
	M.	9·45
	H.	9·50
G. W. P. signifies Great Western Main line.	M.	9·55
	G. W. P.	9·58
	G. W. and D. K.	10·1

EXTRACT No. 2.—WIDENED LINES.

NOTE.	Description.	Arrive at Moorgate Street.
		A.M.
Mid. signifies Midland train.	Mid. T.	9·2
	G. N. P. T.	..
	L. C. and D. M.	9·7
	G. N. P. T.	9·11
	L. C. & D., C. P.	9·14
	G. N. P. T.	9·16
	Mid. T.	9·18
G. N. „ Great Northern train.	L. C. & D. M.	9·21
	G. N. P. T.	9·24
	L. C. & D. T.	..
	G. N. P. T.	9·28
	L. C. & D. M.	9·30
L. C. D. „ London, Chatham, and Dover trains.	Mid. T.	9·32
	G. N. P. T.	9·34
	G. N. P. T.	9·38
	Mid. T.	9·43
	L. C. & D. M.	9·45
	G. N. P. T.	9·45
	L. C. & D., C. P.	9·51
	G. N. P. T.	9·53
	Mid. T.	9·55
	L. C. & D. M.	9·58

The total number of trains using the Moorgate Street Station daily is as follows :—

MAIN LINE.

Description of Train.	Up.	Down.	Total.
Metropolitan	116	116	232
District	38	38	76
Addison Road (G. W. and D. Joint)	32	32	64
Great Western, Main line	7	7	14
Total	193	193	386

WIDENED LINES.

Description of Train.	Up.	Down.	Total.
Midland	49	49	98
Great Northern	62	62	124
L. C. and D.	80	80	160
Total	191	191	382

Total number of trains 768 per day.

As each arriving and departing train requires a separate movement of the engine, for changing from one end of the station to the other, this gives a total of 1,536 movements of engines, on the four lines of way in nineteen hours, and every movement has to be distinctly and separately signalled. This of course could not be done without the aid of electric instruments, to enable the signalmen to communicate with each other, and to have a constant record on the face of the instruments to show what is being done at the time even by themselves.

On the Great Eastern railway 220 trains and engines per day pass on the same metals between Bethnal Green Junction and Stratford. The trains at that part of the line all travel at nearly the same speed.

Where there is a mixture of fast passenger trains with slower goods traffic, and with suburban traffic, new elements come into play. It may be premised that there is a great difference between the number of trains which can be started from a terminus on the same metals and the number which can arrive on the same metals, for the simple reason that trains may be started with almost absolute punctuality, and so preserve their intended distances from each other; whereas, in arriving, the fast trains will overtake the slower ones, and the punctuality is less certain, and so the same regularity cannot be secured: consequently, several railways are furnished with a third line of rails for trains arriving in London. On the Brighton line, for instance, there is a third line for arriving trains from Balham Junction to Victoria Station, Fig. 142. The third line enables the fast traffic to clear five stations in the last 6 miles of the journey, and as many suburban trains *en route*. During the day of twenty-four hours, 34 trains pass along this third line, and 88 trains on the slow line. All the trains, from Clapham Junction to Balham Junction, 127 in number, are despatched by one line.

A further step in this part of the subject is illustrated by the Great Northern and the London and North-Western railways, both of which have a fast passenger service and also a large coal traffic. It is obvious that this is quite different from the stereotyped traffic and speed of such railways as the Metropolitan or North London, and on both the Great Northern and the London and North-Western liberal arrangements are made for separating —not so much the goods traffic from the passenger traffic, as for separating the fast trains from the slow ones.

On the Great Northern, Fig. 143, passing places are provided from Hitchin to Stevenage, 3½ miles, from Hatfield to Potter's Bar,

5 miles, and from Wood Green to Caledonian Junction, 5 miles—all on parts of the line free from tunnels or other expensive works. In the diagram the passing places or slow lines, and also the branch rails, are shown by a full line, and the main rails by dotted lines. When a coal train arrives at one of these passing places, if the main line is clear and no fast train is expected, the coal or goods train is allowed to go by the main line; but if any fast train is expected, the coal train is directed by the signalman through the facing points on to the side line. When the slow train arrives at the south end of any passing place, it is allowed by the signalman to rejoin the main line, under the protection of the block telegraph. At Hitchin and at Hatfield such long passing places are provided only on the up-line, the up-traffic being most in need of them, inasmuch as the coal trains are heavy on the up-journey and empty on the down; and also punctuality is less certain in the arriving than in the departing trains. On the line between Holloway and Finsbury Park, 56 trains per day are passed over the down main line, and 78 trains per day over the down side line—total 134; and 67 trains over the up main, and 74 trains over the up side—total 141; exclusive in both cases of specials and light engines. This shows a moderate number of trains over each line; but the mere numerical reduction of the number of trains does not represent the whole benefit. The greatest advantage is gained by sorting the trains, so that the trains on the same line are more nearly of the same speed, and consequently preserve more nearly their intended intervals of time and space. At Holloway the accommodation is still further increased by the addition of more lines, and thus along 2 miles of the up through line there are only 25 trains per day, chiefly the express trains from York and Manchester. The fast traffic is thus released from obstruction by goods or coal trains: these latter wait in the Holloway sidings, until such time as convenient intervals between passenger trains admit of their being passed through the tunnel to the goods yard. The junctions at Edgware, Highbury, and Enfield are specially worthy of notice, as they are arranged so as to avoid an up branch line crossing a down main, or a down branch crossing an up main line. At Highbury Junction the line to Highbury leaves the up slow line on the level, and the line from Highbury descends, and passes under the main line at Holloway, curves round and joins the down slow line. At Edgware Junction the down branch line strikes off from the down slow line to the left on the level; the up branch line, which must cross the down main line, does not cross it on the level, but is carried up an incline and crosses over the

main lines by a bridge, it then descends and sweeps round into the up slow line. At Enfield Junction the up branch line approaches the up slow line on the level, and the down branch leaves the down slow line by a curve, and ascends an incline and crosses the main lines by a bridge. At each of these junctions the level crossing usual at ordinary junctions is avoided, and the effect is to release the 141 up trains and 56 down trains from having to run the gauntlet of about 60 trains of the Highbury and Enfield branches, and to release the 134 down main trains and 25 up main trains from having to be crossed by about 30 up trains from Barnet. Many other junctions on the Great Northern, London and Brighton, and other railways, are arranged on the same plan.

On the London and North-Western an additional up line, Fig. 144, has been for some years in operation from Bletchley to King's Langley and from Watford to Willesden, the only interruption being caused by the Watford Tunnel, through which there are but two lines. An additional tunnel has now been made, and very shortly the third line will be complete from Bletchley to Willesden. The fast passenger traffic goes by the main line, and the slow passenger traffic and most of the goods and coal trains by the up slow line, but some express goods trains go by the main up line. The total number of down trains is now 91 on the same metals, exclusive of specials and light engines; on the up main line there are 31 passenger and 8 goods trains, and the on up slow line 57 goods and 11 passenger trains; but these relative numbers are variable, because the station-masters have a discretionary power to send any train by either line as circumstances may require. When the new fourth line, now making from Willesden to Bletchley, 43 miles, is finished, the intention is to work them as shown on Fig. 145. All through passenger trains, and some through goods, will go by the fast lines. The slower trains of all kinds will go by the slow lines. This sub-division of the traffic will increase the carrying power of the railway in a much greater ratio than the increased number of lines, for the reasons before referred to. Probably two pairs of rails would carry four times as much traffic as one pair would do with the same minimum intervals between them. It is intended to have all goods yards as far as possible on the east, or slow side of the railway, so as to keep shunting operations as much as possible out of the way of the fast lines. It is proposed shortly to complete the four lines of way to Euston Station on the south, and to Roade on the north. A duplicate tunnel has already been made side by side with the Kensal Green Tunnel; and, indeed, the four lines

are completed as far as the face of Primrose Hill Tunnel. An additional up line is in use from Nuneaton to Rugby, 14 miles. Additional up and down lines are in use from Huyton to Edge Hill, and in course of construction from Stafford to Crewe. In all these cases two lines will be appropriated to fast traffic and two lines to slow traffic. Between Stafford and Crewe the fast lines will be to the east and the slow lines to the west, as the existing goods accommodation is chiefly on the west side.

By the kindness of Mr. Johnson, M. Inst. C.E., Chief Engineer of the Great Northern railway, the author is enabled to give some particulars as to the cost of the passing places on that line:—

GREAT NORTHERN RAILWAY.

Miles.		
	Cost of additional up and down lines between Copenhagen Tunnel and Wood Green, including alterations of stations	£208,734
*3¼	Ditto of up line between Hitchin and Stevenage . .	11,406
	Per mile .	3,258
*5	Ditto of up line between Hatfield and Potter's Bar . .	20,291
	Per mile .	4,058
	Ditto of down line between Hatfield and Welwyn Junction for Luton traffic	6,069
		£246,500

32	Probable cost to complete four lines, King's Cross to Hitchin	£1,000,000
	Per mile .	31,275

The items marked with an asterisk (*) are strictly speaking passing places for fast and slow traffic. The sites were selected as being free from tunnels or other expensive works. The cost of the land is not included, as it was already in the possession of the company, but even so £4,000 per mile must be considered a moderate sum. To make four complete lines from Hitchin to King's Cross would be very costly, owing to the large proportion of tunnel work.

Mr. Baker, M. Inst. C.E., Chief Engineer of the London and North-Western railway, has obligingly communicated the cost of the third line from Bletchley to Willesden, 43 miles, as being £350,000, or about £8,000 per mile. This is also a moderate sum, for in making long passing places there is not the same opportunity of choice of site as in making short ones, and some expensive works must be incurred. The estimate for completing four lines, from Camden to Bletchley is £980,000.

Separate Goods Yards.

The general adoption of separate goods yards, away from the main line, and communicating only with it at the ends, is likely to do a great deal in the direction of taking goods traffic out of the way of the passenger traffic. A good example of this improvement, as carried out at Lincoln by the Great Northern Railway Company, is shown in Fig. 146. The lines marked "old main line" were, until June, 1873, the main lines for all traffic. On each side of the main lines were sidings for making up goods trains, with the usual cross-over and through roads, and of course there was a great deal of shunting going on on the main lines. In the early part of the year 1873, new roads were made for the main line outside of the goods sidings, and with a wide space of ground between the sidings and the main line, which will probably be ample for their extension for some time to come. The traffic from the north arrives at A. Passenger trains go along the new lines to the Lincoln station. Goods trains go into the old lines (small dotted) and are there disposed of by the shunting staff: goods trains ready to go south or north are let out by the signalmen, with due reference to the block system of working. Wherever this improvement of confining the goods traffic to a site on one side of the line only is carried out, the main lines are relieved of a great deal of the cross shunting, now a principal source of delay and danger.

Fig. 147 shows a similar arrangement for the accommodation of coal traffic on the Great Eastern railway at Temple Mills near Stratford. Many similar alterations have recently been carried out by the principal railway companies.

Conclusion.

The advantages of the block and interlocking system scarcely require further proof, than the mention, that the chief railways in England have already adopted it on the busiest parts of their lines, from experience of its necessity.

It secures not only a controlled interval of space, but when distant signals sufficiently far off are used, it secures virtually two intervals of controlled space; and in many cases, even if a driver fails to observe one signal, observance of the next would still preserve him from accident.

As points of detail, attention should be directed to :—

Identity of type of signal for trains on their journey.

Identity of type of signal for shunting purposes in station yards.

Identity of meaning of signals, viz., "stop" and "go on."

Identity of arrangement of adjacent signals, the high speed or main line to be the highest signal.

As a rule signals should be placed to "safety" (if the line is clear) before an expected train comes in sight. The practice of keeping signals at "danger" until they are "whistled off" by the drivers is apt to lead drivers to be too venturesome, in running up to signals without sufficiently reducing the speed of their trains.

The protection of all switches, whether facing or trailing, by interlocking apparatus of few parts and simple construction.

The protection of all facing switches by locking bars.

The use of detector bolts to ascertain that the switches are fully set as intended.

Distant signals sufficiently in advance of the point of danger, and, where necessary, furnished with repeaters.

Separate distant signal arms for each home signal.

The use of "stop" and "advance" signals for the relief of station yards, by enabling trains to stand outside the station under protection of signals.

Free use of loop lines to enable fast and slow traffic to clear each other.

Wherever possible, separate goods yards for shunting purposes should be provided.

At remote stations the use of the fixed signals is sometimes omitted altogether; and then when required they are apt to be unobserved.

Also the taking out of locks from the interlocking apparatus at such times as races and fairs should be not only prohibited but prevented.

At places of light work the hours of signalmen should be sufficiently long to make a day's work.

At places of constant work the hours of signalmen should be varied according to the time of day or night, and according to the severity of the traffic.

The usual wages of signalmen vary from 18*s.* to 28*s.* per week, a rate of pay which cannot be said to be out of proportion to the not very highly skilled class of labour required. Any attempt to give an exceptionally high rate of pay to signalmen would be apt to lead to an artificial class forcing their way into the service to its certain disadvantage.

Many of the railway companies give a gratuity every six months to signalmen who have acquitted themselves without fault. This plan seems a good one, as it effectively passes in review the conduct of all from time to time, and so leads to a painstaking service, quite as much for the sake of the credit attaching to success, as for the sake of the pecuniary reward.

On most lines of railway, a book is kept in each signal box, in which is recorded the actual time of passing of each train, with its number and destination, and any remarks which circumstances may require.

Each signal box ought to be visited by an inspector every day, to see that the men and the machinery are in proper order, and it is a good plan for him to record the time of his visit in the train book.

That all intended movements of bodies in such rapid motion as railway trains should be clearly signalled well in advance is now universally allowed. The means of effecting this signalling are now complete, and the checks against accidental mistakes are such as to reduce the effects of error, whether on the part of the person signalling, or on the part of the person signalled to, to a minimum.

Selection of Signalmen.

All men are not constituted by nature for signalmen; consequently much care is requisite in their selection and training. The Metropolitan railway may be taken as an instance, and perhaps as an example. If an applicant is accepted as a candidate, he has first to undergo a drill of two hours per day for three months. After that he has to go on permanent, but not responsible, duty under supervision until he has performed the duty for fourteen clear days without once requiring the assistance of the responsible signalman. He is then appointed to some intermediate signal box, and his wages are raised from the previous rate of 18*s.* per week as a porter, to 22*s.* as a signalman, with a bonus for good conduct equal to 2*s.* per week more. Every signalman is required to know the working of the signal box on each side of him in addition to his own.

Promotion takes place from intermediate or inferior to more important stations, with a constant advance of pay up to 30*s.* per week. It frequently happens, however, that even very good signalmen decline promotion to the highest places where the traffic is incessant, and requires strong nerves and clear heads.

The bonus is paid quarterly in sums of 25*s.* each, conditionally

upon no mistake having been made during the quarter. So carefully selected and trained, and so well conducted are the signalmen as a rule, that on the Metropolitan railway, there have not been in ten years more than three instances of failure to obtain the bonus, notwithstanding the strictness of the quarterly investigation.

About one-third of the signalmen on the Metropolitan railway have been sailors. It is found that sailors make excellent signalmen, but soldiers do not.

Cost of the Interlocking and Block System.

It is almost impossible to ascertain what has been the total cost of the interlocking and block system on any given railway, because the work has been done sometimes on revenue account and sometimes on capital account, and is always more or less mixed up with other work.

A fair estimate, however, may be made as follows :—

Cost per Signal Station.

15 levers @ £8	£120
15 sets connections @ £7	105
Signal house	60
Block telegraph instruments and wires	60
	15) 345
Per lever	£23

The cost of complete interlocking apparatus, exclusive of the signals themselves, which would be used in any case, but inclusive of the necessary signal house, and of the block telegraph apparatus, does not exceed £20 per lever on an average, and £25 per lever may be taken as an outside estimate.

The number of levers required is approximately as follows :—

For a level crossing, where one railway crosses another, 8 levers.

For an ordinary junction of double lines 10 levers are required.

For a small station, 10 or 12 levers.

For a medium station, two frames, each with 20 levers.

For an important station and junction combined, perhaps three or four frames, of 20 to 70 levers each, averaging perhaps 40 in each frame.

Some idea of the gross cost of interlocking, as compared with the whole cost of a railway, may be derived from Table 148.

Fourteen railways, having a gross mileage of 10,160 miles, have, by the Board of Trade returns (for the year 1873), 19,394 points of communication with the metals of the passenger lines, either by

TABLE 148.—ESTIMATED FIRST COST OF INTERLOCKING AND BLOCK SYSTEM OVER AND ABOVE COST OF SIGNALS.

1. Company.	2. Miles.	3. *Actual Number of Connections in Passenger Lines.	4. Probable total Signal and Point Levers required.	5. Cost per Lever, including Gear and Telegraph.	6. Total Cost of Interlocking and Block.	7. Whole Cost of Railway.	8. Percentage Column 6 of Column 7.	9. Company.
				£.	£.	£.		
L. N. W. Ry.	1,539	3,132	15,660	25	391,500	71,604,143	·55	L. N. W. Ry.
Per Mile		2·04	10·2		255	46,526		*Per Mile.*
G. W. Ry.	1,402	2,460	12,300	25	307,500	51,339,713	·6	G. W. Ry.
Per Mile		1·75	8·75		219	36,620		*Per Mile.*
N. E. Ry.	1,337	2,399	11,995	25	299,875	44,875,111	·66	N. E. Ry.
Per Mile		1·8	9·0		225	33,564		*Per Mile.*
Midland Ry.	1,024	2,099	10,495	25	262,375	45,791,413	·59	Midland Ry.
Per Mile		2·05	10·25		256	44,718		*Per Mile.*
G. E. Ry.	833	1,587	7,935	25	198,375	32,495,478	·61	G. E. Ry.
Per Mile		1·9	9·5		238	39,000		*Per Mile.*
N. B. Ry.	831	1,444	7,220	25	180,500	24,164,417	·79	N. B. Ry.
Per Mile		1·74	8·7		217	29,080		*Per Mile.*
Caledonian Ry.	797	1,328	6,640	25	166,000	23,195,669	·71	Caledonian Ry.
Per Mile		1·6	8·0		200	29,090		*Per Mile.*
G. N. Ry.	578	1,166	5,830	25	145,750	21,122,044	·69	G. N. Ry.
Per Mile		2·03	10·15		254	36,540		*Per Mile.*
L. and Y. Ry.	446	1,478	7,390	25	184,750	24,253,849	·76	L. & Y. Ry.
Per Mile		3·31	16·55		413	54,380		*Per Mile.*
L. B. & S. C. Ry.	345	593	2,965	25	74,125	20,537,675	·36	L. B. & S. C. Ry.
Per Mile		1·43	7·15		179	59,530		*Per Mile.*
M. S. & L. Ry.	258	758	3,790	25	94,750	18,117,249	·41	M. S. & L. Ry.
Per Mile		2·94	14·70		367	70,200		*Per Mile.*
S. E. Ry.	327	669	3,345	25	83,625	19,706,107	·43	S. E. Ry.
Per Mile		2·05	10·25		256	60,260		*Per Mile.*
Highland Ry.	335	241	1,205	25	30,125	3,522,060	·85	Highland Ry.
Per Mile		·72	3·60		90	10,510		*Per Mile.*
Metropol. Ry.	7½	40	400	50	20,000	8,359,655	·23	Metropol. Ry.
Per Mile		5·3	53·00		2,666	1,114,620		*Per Mile.*
Totals	10,160	19,394	96,970	..	2,439,250	409,084,577	·6	Totals.
Averages per Mile	..	1·92	9·6	..	240	40,264	..	*Averages per Mile.*

* The numbers given in Column 3 are the numbers returned by the Companies to the Board of Trade in 1872–73. All other particulars are taken for the same period.

TABLE 149.—TABLE SHOWING PROBABLE ANNUAL COST OF ADDITIONAL ATTENDANCE AND MAINTENANCE OF INTERLOCKING AND BLOCK SYSTEM.

1. Name of Company.	2. Miles of Line.	3. Levers taken from Table 148.	4. No. of Signal Stations.	5. Men per Signal Station.	6. Total Men.	7. Total Additional Men.	8. Wages, Interest and Maintenance per Man per Annum.	9. Total Additional Cost per Annum.	10. Total Traffic per Annum.	11. Per Cent. Column 9 of Col. 10.	12. Annual Increase of Traffic Receipts.	13. Total Ordinary Capital.	14. Per Cent. Column 9. of Col. 13.	15. Total Capital.	16. Per Cent. Column 9 of Col. 15.	17. Name of Company.
							£.	£.	£.		£.	£.		£.		
L. N. W. Ry.	1,539	15,660	1,044	3	3,132	1,566	100	156,600	8,119,832	1·9	541,177	36,862,269	·42	71,604,143	·22	L. N. W. Ry.
Per Mile		10·2				1·02		102	5,276							*Per Mile.*
G. W. Ry.	1,402	12,300	820	3	2,460	1,230	100	123,000	4,984,052	2·5	330,000	13,761,514	·89	51,339,713	·24	G. W. Ry.
Per Mile		8·75				0·88		88	3,555							*Per Mile.*
N. E. Ry.	1,337	11,995	800	3	2,400	1,200	100	120,000	5,434,963	2·2	401,337	17,229,933	·72	44,875,111	·27	N. E. Ry.
Per Mile		9·0				0·9		90	4,065							*Per Mile.*
Midland Ry.	1,024	10,495	709	3	2,100	1,050	100	105,000	5,134,213	2·4	567,162	17,094,307	·61	45,791,413	·23	Midland Ry.
Per Mile		10·25				1·02		102	5,014							*Per Mile.*
G. E. Ry.	833	7,935	529	2	1,058	529	100	52,900	2,462,764	2·1	123,577	12,428,926	·42	32,495,478	·16	G. E. Ry.
Per Mile		9·5				0·63		95	2,957							*Per Mile.*
N. B. Ry.	831	7,220	481	2·5	1,203	602	100	60,200	1,825,908	3·3	133,341	5,096,430	1·20	24,164,417	·25	N. B. Ry.
Per Mile		8·7				0·72		87	2,200							*Per Mile.*
Caledonian Ry.	797	6,640	443	2·5	1,106	553	100	55,300	2,539,405	2·2	216,384	7,976,002	·69	23,195,669	·24	Caledonian Ry.
Per Mile		8·0				0·7		80	3,187							*Per Mile.*
G. N. Ry.	598	5,830	389	3	1,167	584	100	58,400	2,557,314	2·3	140,937	11,364,537	·49	21,122,044	·28	G. N. Ry.
Per Mile		9·75				0·98		101	4,277							*Per Mile.*
L. and Y. Ry.	446	7,390	493	3	1,479	740	100	74,000	3,212,002	2·3	265,788	13,334,594	·55	24,253,849	·30	L. and Y. Ry.
Per Mile		16·55				1·7		166	7,202							*Per Mile.*
L. B. & S. C. Ry.	345	2,965	198	2·5	495	248	100	24,800	1,514,195	1·6	112,743	8,191,709	·30	20,537,675	·12	L. B. & S. C. Ry.
Per Mile		7·15				0·72		71	4,400							*Per Mile.*
M. S. & L. Ry.	258	3,790	253	3	759	380	100	38,000	1,483,824	2·6	130,000	6,233,573	·60	18,117,249	·21	M. S. & L. Ry.
Per Mile		14·70				1·5		147	5,751							*Per Mile.*
S. E. Ry.	377	3,345	223	3	669	335	100	33,500	1,736,483	1·9	124,633	8,320,095	·40	19,706,101	·17	S. E. Ry.
Per Mile		10·25				·9		102	4,600							*Per Mile.*
Highland Ry.	335	1,205	80	2	160	80	100	8,000	283,254	2·8	23,214	1,688,441	·47	3,522,060	·22	Highland Ry.
Per Mile		3·60				·24		36	844							*Per Mile.*
Metropol. Ry.	7½	400	25	3	75	..	120	9,000	466,976	1·9	68,595	4,308,370	·21	8,359,655	·11	Metropol. Ry.
Per Mile		53·00						1,200	62,263							*Per Mile.*
Total Miles of Line.	10,160	97,145	6,478	..	..	..	..	918,700	41,755,190	2·2	3,178,888	164,419,070	·56	409,084,577	·23	Total Miles of Line.
Per Mile	..	9·3	·64	..	1·8	·9	..	90	4,110	..	313	..	..	..	..	*Per Mile.*
	Percentages if cost of half the accidents is taken into account (Page 188).									·8			·20		·08	

to face p. 186.

level crossing or by switches. Now, allowing 3 signals as an average to every such set of switches, there would be a total of 19,394 switch levers, and 58,182 signal levers, together 77,576 levers; and, allowing also an equal number of switches not communicating directly with the main line, but which would have to be connected to the apparatus, the gross total would be 96,970 levers; and this number, divided by 10,160 miles, gives an average of 9·6, or nearly 10 levers per mile. Now 10 levers multiplied by £25 each gives £250 per mile as the cost of interlocking and block telegraph apparatus, equal to about ½ per cent. on the total cost of the railways.

The cost of signal work is generally very much greater per mile on the railways of higher cost, or of larger traffic, such as the Metropolitan or the Charing Cross; but it is a lower proportion of the whole cost of the railway.

Cost of Maintenance and Attendance.

If the average number of levers in each signal-box be taken as 15, and three men be allowed to each box, including inspectors and extra men, this would make one man to every 5 levers. Now 10 levers are, in the last calculation, the complement of a mile of railway; so two signalmen to every mile of railway would be required.

The number of signal stations and the number of men required by this calculation agree almost exactly with the actual facts, as follows:—

On the Great Northern railway from London to Askern there are 109 block-signal stations in 162 miles; and at the rate of three men per station, this would require three hundred and twenty-seven men for 162 miles = 2 men per mile.

On the London and North-Western railway from London to Stafford, 132 miles, there are 88 block-signal stations; and at the rate of three men per station the total number would be two hundred and sixty-four for 132 miles, or exactly two men per mile.

On the one hand some persons argue that the gathering together of switch and signal levers, enables one signalman on the new system to do the duty of several pointsmen on the old. On the other hand some persons are of opinion that all the signalmen are really additional men. A view somewhere between these two is most probably the correct one The following calculation is based on the supposition that half of the whole number of men required would be additional men; that is to say, one additional man per mile of railway.

The annual cost of attendance and maintenance, based on the busiest parts of two of the busiest railways, would then stand as follows:—

	Per Annum. £.	s.	d.
Wages of signalman at 24s. per week	60	0	0
Cost of maintenance of apparatus 10 per cent. on £250	25	0	0
Five per cent. interest on first cost	12	10	0
Total .	£97	10	0 per annum per mile as an average cost.

Table 149 gives the probable maximum number of signalmen per mile, the probable additional number, and the cost of wages and maintenance per mile, compared with the gross traffic receipts.

It is observable that the railway which has nearly twice the average need of protection, viz., the Lancashire and Yorkshire, and which would require nearly twice the average number of men per mile, shows a lower percentage of cost compared with traffic receipts than some of the other lines. This is a satisfactory feature, as showing that the more business there is on a line, and the more need it has of safeguards, the better worth while is it to provide them.

The gross traffic returns of the twelve railways in the Table amounted to £41,755,190 last year. This sum, divided by the number of miles, gives an average of £4,110 per mile per annum.

The cost of the block system, being £100 per mile per annum, would thus be 2·2 per cent. of the total receipts.

It is also fair to take into account that more than half the accidents of recent years would probably have been prevented if the block and interlocking system had been universally in use. For some years the fourteen railway companies mentioned in the tables have paid as compensation for injury to passengers and goods the sum of £430,700: to this may be added at least a like sum for destruction of the companies' own property. The accident account would probably then be as follows:—

Annual sum paid as compensation . . .		£430,700
Loss by destruction of companies' property . .		430,700
Loss by delays—50% on the money paid as compensation		215,350
Law expenses, including cost of companies' own board investigations . . .	25% on the money paid as compensation	107,675
		£1,184,425

The Author submits that at any rate half of this sum, viz.,

£592,212, may be set off against the annual cost of the block system, £928,700, and this leaves £336,490 per annum as the net annual cost.

Compared with the gross traffic receipts, this gives the insignificant percentage of ·8 per annum. This may be said to represent the demands of the Government upon the railway companies whenever any compulsory law on the subject of interlocking, &c., may be passed.

It is noteworthy that, whilst such a law is talked of, the Railway Companies are at the same time making a demand on the Government for the repeal of the passenger tax.

The Author would suggest that any compulsory law on the one subject should be accompanied by a just relief on the other. The Companies would thus be enabled to carry out these improvements without loss to themselves, to the great advantage of the travelling public, and with only the slight sacrifice which the public revenue is now so well able to afford.

As another source of ways and means for reimbursement for the cost of the universal adoption of the improvements indicated, there is given in Table 149 a column showing the average annual increase of traffic receipts,—an increase at an *annual* rate of about ten times the net cost of the block system.

The Author has thus endeavoured to fulfil the task of describing the various steps by which the present fabric of railway signalling has been built up; and in travelling over forty years of time, and over ground on which such varied opinions are found, he cannot but feel that the result of his labours must necessarily be far from perfect.

In estimating the cost of accidents he has omitted to speak of the destruction of life and limb which might be mitigated, for the simple reason that he wished to steer clear of what may be called the sentimental part of the subject, and to keep rather to the facts easily ascertainable and to arguments easily demonstrable.

Careful and dispassionate examination will assuredly show, that, on the one hand, much more has already been done by the railway companies than the travelling public have any idea of—as witness the Great Northern, the London and North-Western, the Metropolitan and other leading railways—and, on the other hand, that the most extreme demands of the public will be found after all to be no very serious tax upon the railway property of this country.

The Paper is illustrated by a series of diagrams, from which Plates 27 to 31 have been compiled.

[Mr. RAPIER

Mr. Rapier desired to thank numerous friends for the valuable assistance rendered in the compilation of the Paper and the preparation of the drawings. He had only sought to bring forward instances of what had been accomplished, without pretending to make the Paper exhaustive. On many points connected with railway signalling great difference of opinion prevailed, and on none more so than on the subject of permanent audible signals. He had alluded to the probability that if signals were all arranged so as to give the drivers an audible signal in addition to the visible signal, they would entirely rely on the former, and be less careful in looking out for the latter. He had, however, within the last few days had an opportunity of examining on the London and South-Western railway the first *optional* audible signal; this Mr. Burn had erected since the reading of the Paper. The apparatus enabled a signalman to sound the whistle of an approaching engine if the visible signals should be obscured by fog, or if for any other reason the signalman were especially anxious to attract the driver's attention. The signal could of course be arranged either as a negative or a positive one. It might be a rule that no driver should proceed past a signal station in foggy weather without receiving an audible signal. Indeed at present the rule was that if a driver was in doubt as to the signal he was to pull up and ascertain—a rule which it was not always possible to obey.

It had been urged as an objection against interlocking apparatus that a man was apt to get puzzled with having so many levers to attend to. Now the contrary was the fact. A man might be puzzled in having a warm corner to look after, but not by the number of levers. Indeed, the more the better, as, when fully furnished with gear, the man had only one separate thing to do by one separate movement of his own, and had also the protection of the mechanism against mistakes which might involve danger.

The complete equipment of railways with the efficient appliances of the block system had a direct relationship with the dividend-earning power of railways. The question which he was anxious to see thoroughly raised was what was the maximum amount of traffic which could be carried on one pair of metals. If twenty or thirty trains could pass over one pair of metals on the Metropolitan railway in an hour, what were the circumstances limiting the number of trains in the case of other railways? Differences of speed at once intervened, and the question was how to accommodate those differences. The old ten-minutes' interval of the Great Western would obviously be of little service now. But the new-

fashioned interval of space would do everything, giving as it did the power to pass trains over a given spot within about a minute and a half of each other. The absolute block system, therefore, was that by which a railway could get through the greatest amount of dividend-earning work. He had endeavoured to show in the tables the probable cost of the absolute block system. In the Paper he had taken a low average number of levers in a signal-house (fifteen), which made it appear more costly, because the signal-house and the block telegraph instruments were more costly, in proportion, for a small frame than for a larger one. The amount he had calculated was £25 per lever, which would probably be called in question, by some as being too high, and by others as being too low. The numbers of points given in Table 148 were taken from the Parliamentary Returns of fourteen railway companies. The London and North-Western railway returned 3,132 points of communication on its passenger lines. Taking the high average of three signals for each switch, and allowing for a subordinate switch not actually in the main line, but which would have to be coupled up to the locking frame as well as the parent one, the number of levers would be 15,000, or 10·2 per mile. The Lancashire and Yorkshire railway had 16·55 per mile. The total first cost per mile was shown in Table 148.

Table 149 showed the probable annual cost of maintenance and additional attendance. It gave the number of levers and the probable number of signal stations. The probable correctness of the estimate as to the number of signal stations was curiously confirmed by the London and North-Western railway, London to Stafford, and the Great Northern railway, London to Askern, on both of which portions of railway the numbers very nearly accorded with his own calculation, viz., one signal station to every mile and a half of railway on an average. With regard to the number of men, it was much disputed whether the interlocking and the block system required more men or fewer. On the one hand, it was argued that by doing away with so many ground pointsmen the work could be done with fewer men; on the other hand, it was said that the signalmen were all new men. He had taken a mean between the two, and supposed that half the total men were new men, which he believed to be slightly above the fact. With regard to the wages, interest, and maintenance of gear, he had calculated £100 per man per annum, and he had shown, in Table 149, the probable additional cost per mile per annum, the London and North-Western being £102, and the Lancashire and Yorkshire £166 per mile per annum. When, how-

ever, the additional cost was compared with the very high traffic receipts of the Lancashire and Yorkshire railway, the annual cost of the block system per cent. of traffic receipts was less than the percentage on some other railways. He had given a comparison of the block system with the whole traffic, and also the annual increase of the traffic receipts on an average of two years. In the case of the Midland railway it would be seen that there was an increase of £567,000 per annum year after year. If the traffic receipts increased at the rate of 11 or 12 per cent., as in the case of the Midland, or say 8 per cent. all round, it was clear that it would be necessary to face the question how to get the best possible result out of the existing railways.

He had next compared the annual cost with the total ordinary capital, for the shareholder might naturally inquire what the cost of the system would be in the shape of reduced dividend in the first instance. He had next shown the total capital with which it was most fitting to make a comparison. If the original capital were small as compared with the total capital, as in the case of the Great Western (£13,000,000 as compared with £51,000,000), a slight improvement in the profit would affect the ordinary capital, and so would a slight disadvantage in the shape of expense; and if the original shareholders were anxious to gain the one they should be willing to incur the other. The true way was to compare the first cost of the block system with the whole cost of the railway, and the annual maintenance also with the whole capital. The calculations as to the cost of the block system were exclusive of the signals themselves, which would be used in any case, and also exclusive of sidings or additional accommodation, because the cost of additional sidings did not properly belong to the block system. If the system were carried out, it would enable a railway to be worked with less siding room, the same regard being paid in both cases to safe intervals of trains, since it enabled the main line to be more fully and constantly occupied.

After the block system had been carried out, the next thing would be to make additional lines. One way was to make new lines through fresh districts, affording alternative routes, but involving new stations, new staff, and, in fact, a new railway altogether. Such lines might be of two sorts, like that between Lincoln and Honington, forming an important auxiliary for sending the coal traffic, but not shortening the main line; or, like several lines which had been made on the Midland, shortening the main line of railway, as in the case of the line from Chesterfield to Sheffield, and from Trent to Chesterfield, the line from Don-

caster to York on the North-Eastern, and the Team Valley line, both the latter affording additional facilities for fast traffic, and going through a new district. Another mode of making additional lines was the system of passing-places, adopted by the Great Northern Company, Fig. 143. By the kindness of Mr. Johnson, chief engineer of that railway, he was enabled to give some information as to the cost of such passing-places. The additional works at Holloway had cost £208,000, but that was not, properly speaking, a passing-place. It might rather be called a terminal accommodation. The lines from Hitchin to Stevenage and from Hatfield to Potter's Bar were, strictly speaking, fast and slow passing-places. The 3½ miles from Hitchin to Stevenage cost £11,000, or £3,200 per mile. The up-line between Hatfield and Potter's Bar cost £20,000 for 5 miles, or £4,000 per mile. The statements as to the cost did not include land in the case of the Great Northern and the London and North-Western Companies. Next came the system of four lines. The cost of converting the passing-places into four lines on the London and North-Western railway would be £980,000. The cost of the previous passing-places, or third line, had been £350,000. The probable cost of completing the four lines on the Great Northern, for the 32 miles from King's Cross to Hitchin, would be about £1,000,000.

There was a great outcry for separate lines for goods and other slow trains, distinct from the fast traffic lines, but it was, for the present, in his opinion, premature. Perhaps in twenty years the London and North-Western might be doubled all the way between London and Liverpool, but now the right method appeared to be to provide additional accommodation where it could be done cheaply. It would not do to lessen the speed. If any one of the three great companies guaranteed to spend two hours longer between London and Edinburgh, it would be about the quickest way of going to ruin that could well be devised. He remembered accompanying two elderly, nervous gentlemen to King's Cross to see them off to Edinburgh. They were full of the glories of the old stage-coach era, and talked much of the dreadful railway accidents as a contrast. He tried to calm their fears and said, "The train you are going by does not travel anything like so quickly as the train before it." On arriving at King's Cross, the "Flying Scotchman" had not yet departed. One of his friends said, "Do you really mean to say that that train will get to Edinburgh two hours before we do?" "Yes, I do." "Then, George, we will go by it, and we shall be able to get our dinner comfortably at Edinburgh, instead of half choking ourselves at York." Mr. Rapier

concluded by saying, that he had endeavoured to place the subject as fully and as clearly as possible before the members, without expressing decided opinions of his own, but rather with the hope of eliciting the views of those who were practically engaged in the working of railways.

Mr. Farmer said he desired to make a few observations with regard to the original invention of the locking apparatus. The Author had apologized for omitting to notice the admirable invention of Mr. Buck; but Mr. Farmer had a list of ninety-two patents for locking apparatus taken out by various individuals from 1856 to the present time, many of which, as well as Mr. Buck's, deserved notice. He wished to allude to the contrivances referred to in the Paper as preceding what might be called the original invention of the locking apparatus. That of Mr. Gregory, said to have been in use at the Bricklayers' Arms Station in 1843, was no doubt a meritorious invention as far as it went; but as there was no mechanical communication between the points and the signals, it did not anticipate the interlocking apparatus. The contrivance in use at East Retford, was one of the hares started by the defence in an action brought by his firm against certain infringers of their patent; but it never got beyond the formality of being included in a long list of legal objections to the pleas in the suit. The contrivance prevented a signal being given for traffic from Gainsborough to Manchester, unless the points stood in that direction; but it did not prevent the signal for the branch being given, although the points stood contrary to the branch; it made no pretence to interlock with any of the other signals or points. Mr. Saxby's interlocking system of 1856, for the first time in the history of railways, provided a mechanical reciprocating communication, and action upon all the points and signals of a railway junction, whereby not only those points and signals which were in direct relation with one another were made to work in harmony, but all the other signals of the system were also controlled and locked against improper or dangerous use. The first apparatus, introduced at Bricklayers' Arms, consisted of eight semaphore signals; and there were six pairs of points concentrated within the signal cabin, all so governed and locked that it was impossible to give any signal which was contrary to the position of the points, and it was equally impossible to give any signals which would be in conflict with other signals. He was at a loss to understand how such an invention could have been overlooked, as he ventured to claim for that invention that it was the foundation of the whole existing system. The vital principles of the interlocking apparatus

were two:—(1) simultaneity of working and movement; (2) that the movement of the points should in all cases dominate the signals. These principles had been adopted in every locking apparatus since 1856. Whenever a point lever was moved the locking gear with which it was connected was moved simultaneously, so as to lock all those signals which it would then be dangerous to give in the altered position of the points; and all those signals were set at liberty which it would then be safe to give. With regard to what the Author called a *pari passu* movement of points and signals, that was to a certain extent an element in the patent of 1856, but not an essential one; it was only a matter of convenience, and not of safety—a *pari passu* movement of itself, that was to say, without reciprocating influence on other signals, would be absolutely dangerous. He could not understand how, with such a list of inventions (ninety-two in number) so completely covering the field of mechanical contrivance, the Author had contrived to start "*de novo*," and to produce a locking apparatus of which it might be said *ne plus ultra!*

Mr. Imray said the Paper was like the play of Hamlet with the part of the Prince of Denmark omitted. It would be strange to hear a Paper upon the steam engine without any mention of the name of Watt, or one on railways without an allusion to Stephenson. It was generally admitted that the first inventor of the interlocking apparatus was Saxby, in 1856; but nothing was said of that invention. Many patents had since been taken out for various mechanical details; but the fundamental principle of Saxby's apparatus had not been altered. The apparatus at East Retford, referred to as a locking apparatus, was nothing more than a point indicator. Mr. Saxby was the first in 1856 to put into a row together the levers for working the points and the signals. He was the first to apply to those levers the spring catch arrangement. It had been known before, but no one had thought of applying it to that purpose. In 1860, instead of using rocking shafts for communicating the locking movement, Mr. Saxby adopted sliding bars. Since that time various inventions had been made for conveying the movement by sliding bars or by rocking shafts. Mr. Rapier's method of sliding bars was a mere modification of Saxby's apparatus. In 1867 a completely new principle was introduced, also due to Mr. Saxby. In previous methods the locking was effected by the movement of the lever. The lever had to be moved a certain distance before the other levers were locked, and the result was that when the apparatus got slack the signalman might be able to lower the signal when he ought not to lower it. Mr. Saxby's plan was to effect

the locking by the movement of the spring catch. Before the lever was moved, the mere intention of moving it effected the locking. This was the most important invention of all, for a wrong signal could not be given either by negligence or by any strain or slackness of the apparatus. Before the lever could be moved the spring catch must be closed, which operation effected the necessary locking. Mr. Rapier had alluded to Saxby and Farmer's invention, but only in terms of faint praise. In other respects he valued the Paper highly.

Mr. D. A. Carr said it had been remarked that the worst policy of a railway company would be to reduce the speed of its trains. Mr. Carr ventured to think that if the "Flying Scotchman" had gone through a fog on its way to Edinburgh, not only would it have been two hours late, but possibly it would never have arrived there at all. The Author had enlarged on the existing system of interlocking points and signals; but had only made slight mention of any modes of communicating with the engine-driver in foggy or snowy weather. Mr. Carr had, in conjunction with Mr. Crawford Barlow, endeavoured to fill up that gap, and had made a series of experiments with that object. One defect in the present system was the possibility of a malicious signalman pulling off the points, even though he had received the danger-signal. With the view of meeting that difficulty, a system of electrical signals fixed on the weather-board of the engine had been proposed to take the place of the so-called fixed signals. The arrangement for signalling on to the train itself in connection with the present fixed signals was shown in Fig. 1. C was an intermediate block-signal station, with home and distant signals. At the point where the existing distant signal was first seen, the electrical distant-bar was placed, and there was a second bar about 50 yards nearer the box to repeat the signal received on the engine. At the box there was a longer bar or home signal. The three bars were placed in electrical connection with the signal instrument, Fig. 2, which was worked by the levers. The action was as follows:—The signalman had received notice of the approaching train by means of the block instruments. Should the next block length be clear, he proceeded to pull off the home and the distant signals. In doing so he moved the shades in the signal instrument from red to white, thereby changing the distant and the home signal-bars. The approaching train passed over the distant signal-bar at A, received a "clear" signal, which it repeated on passing B, and proceeded to the home signal-bar, where the clear signal was again received and the train proceeded to the next block station. Should, however, the block length ahead not be clear, the

Fig. 1.

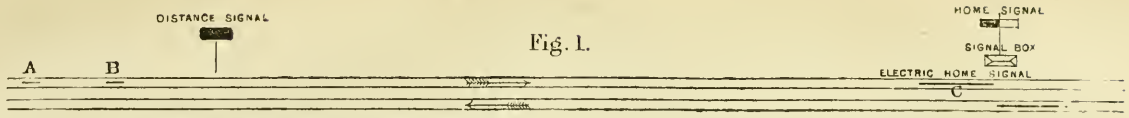


Fig. 2.

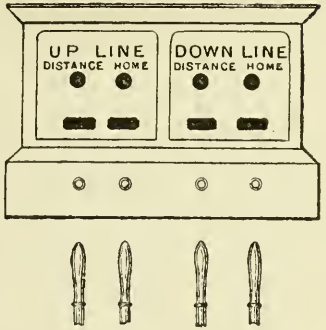


Fig. 4.

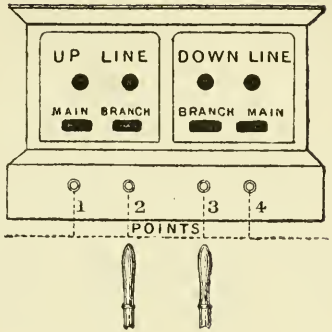
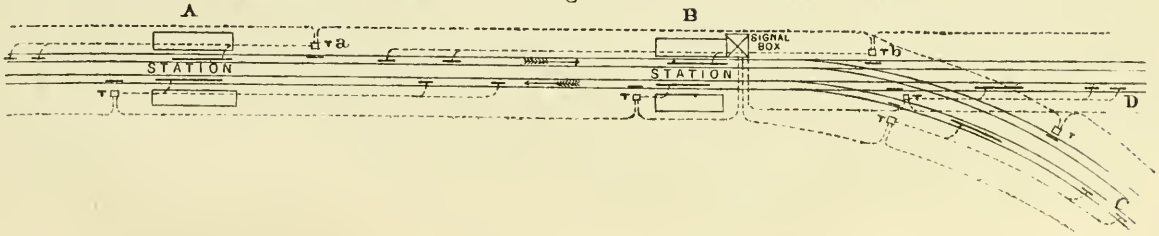


Fig. 3.



signalman left the signals at danger, when the electrical signals also remained at danger. It would be observed that, by means of the repeater, the signalman knew directly the train had come within the distant signal, and could therefore at once cover it. Fig. 3 showed the automatic arrangement for a double junction. A D was a through line with a branch to C. A and B were two stations, fitted with electrical signal-bars, as shown by black lines, and instruments termed transmitters, T. The transmitter was moved by a treadle, depressed by wheels, and a wire passed from transmitter to transmitter, and also to the signal-bars. The action of the train from A to D was as follows:—A train arrived at the distance signal of station A. If the block length was clear between A and B the train received a clear signal, and proceeded past the distance and arrived at the home signal, where it again received a clear signal. It then passed the home signal and arrived at transmitter at *a*, which it depressed in passing, causing bars at A to be set to danger, and at the same time struck an electrical bell in the signal-box at B. What took place in the interior of the signal-box at B, the train being between A and B, was as follows: when the signalman received notice of the approaching train, he depressed the key of the signal instrument marked "Main Line, No. 1," Fig. 4, giving a clear signal to the approaching train; but, as this key was in connection with the wire from the transmitter at *b*, no current was sent into the bars as long as a previous train was travelling between *b* and the block station at D. The instant, however, that the block length between *b* and D was clear, the transmitter at *b* fell, and, the circuit being completed, the bars received the clear signal, which was transmitted on to the approaching train, which then travelled past the distance and home signals as before, and proceeded towards D. If, however, a block had occurred between B and D, the transmitter at *b* had not fallen, and therefore, although the signalman had given "Line Clear," the circuit was not coupled up, and the approaching train received a danger signal at the distant signal, and at once slackened to slow speed, stopping at the home signal at B. For trains travelling in other directions the operation was precisely the same, it being necessary only that if a train was proceeding on to the branch, the switch-handle must first be moved before the signal-key could be depressed. It was to be observed that, as the keys were interlocked, the signalman having depressed the key for the Up Main line, could not depress the keys for the Up Branch No. 2, but could depress either the Down Main Line No. 4 or the Down Branch No. 3, but not both.

Mr. A. R. Poole said, though not a scientific man, he had had

in his professional duties something to do with interlocking apparatus, and had himself made some attempts in that direction. It was not always the patentee who was the inventor: the groundwork might have been laid by another. It might be that the invention was taken up and worked by railway companies, though it had never been patented. All that the public, however, could do was to look into the documents in the Patent Office, to see what was really patented, and this was what he had done. The first groundwork that he had found was the patent of Mr. Saxby, in 1856, for working signals and points simultaneously by means of one lever. Then there was Mr. Saxby's patent of 1858, in which, for the first time, a lever was found locking a lever; but he agreed with the Author in thinking that the real groundwork of all the different kinds of interlocking apparatus there exhibited, and at present in use, was the patent of Austin Chambers of 1859 (Fig. 66). By that, for the first time, signal-levers were brought together and connected with point-levers, and for the first time the action of the signal-lever was found locking the point-lever. But the object was not so much to consider how different inventions excelled others, but what were the requirements of the present day. It was for men of science to say what was wanted; and very often an ordinary workman might supply the necessity. Mr. Saxby's patent of 1860 was, no doubt, a great advance upon Chambers' invention. He was informed that there was also an invention, perhaps a patent, by Mr. Stevens of that date, but he had been unable to find it. He had been told, however, that in principle it was much the same as Mr. Saxby's, though perhaps carried out in a different way. At all events, for a number of years those two gentlemen seemed to have gone on upon these inventions. After seven years' working it was found that the locking was apt to wear out, and that if made strong enough it was too heavy. Another defect was that the unlocking could not be performed at the particular moment when it was required. The two requirements evidently were that the lever should not be locked absolutely by the lock, the leverage being too great, and that there should be some movement, independently of the movement of the lever, which should effect the locking prior and subsequently to the stroke of the lever in performing the actuation of the point or signal. No sooner were these requirements ascertained than they were supplied. Two patents were taken out in March 1867, within three days of one another, one by Mr. Saxby, the other by Mr. Easterbrook, both using the catch rod to obviate the first difficulty. The two gentlemen went to law, and Mr. Saxby was

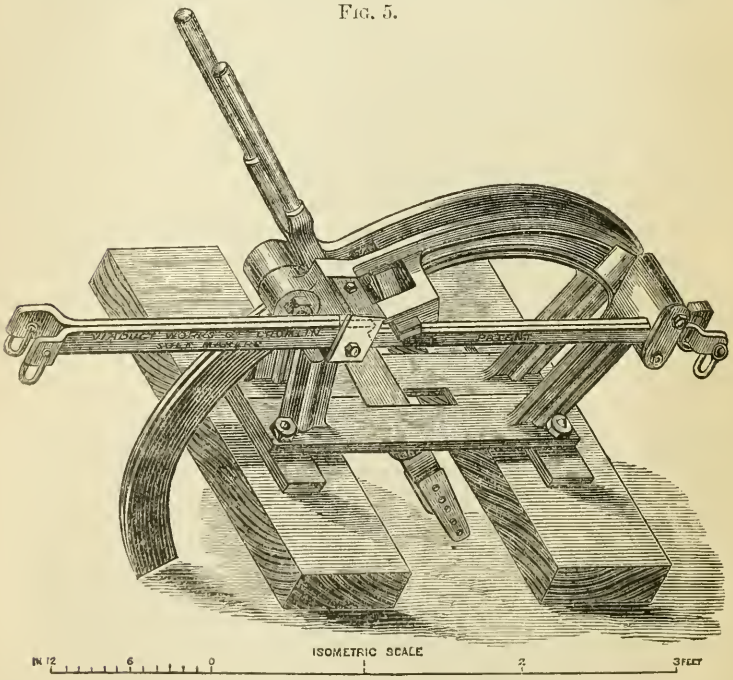
worsted. His patent was three days prior to that of Mr. Easterbrook, but Mr. Easterbrook was left in possession of the patent for locking the catch rod. Another step had yet to be taken, namely, to actuate the locking gear by the catch rod, and that was done three months subsequently. Again two patents came out within three days of each other, Mr. Easterbrook being three days later than Mr. Saxby. The same action was taken, and on this occasion Mr. Easterbrook was worsted. The result was most unsatisfactory to the public. No doubt the two patents were really for one invention. When one part was adopted the other was a necessary consequence; but the inference would seem to be that Mr. Easterbrook could lock his catch rods, and Mr. Saxby could actuate his locking gear by catch rods, but that neither of them could do both; and the public could not do both, because these gentlemen would not agree. Since 1867 various methods had been tried to supply those requirements in other ways. There had been several inventions to lock by what had been called prompt locking. This might possibly do before the stroke, when there was a certain slackness, but it would not do at the end of the stroke when everything was tight. Another objection to 'prompt locking' was that, since the locking took place at the same time as the point or signal of the lever was being actuated, the signalman would often uselessly exert his strength, and perhaps strain the lock, before he discovered that the lever was locked. Other inventions had been tried to obviate the other difficulty to which he had referred, but they did not appear to have answered their purpose. Thinking the matter over, and keeping these two difficulties in view, it occurred to him that he could obtain a motion subsequent and prior to the motion of the lever in actuating the point, which would be equivalent to the motion of the catch rod of Mr. Saxby, and the locked catch rod lever of Mr. Easterbrook. He met the latter difficulty by opposing not the lock itself to the lever in its backward and forward movement, but the top plate. He gave the lever a lateral as well as a backward and forward motion. This required a very slight motion at the fulcrum. The lock only prevented the lateral motion. It would be obvious that, as long as the levers (Fig. 104) were in a recess at the end of the aperture of the top plate, they could not move backwards and forwards. They were kept there by a spring which would give if the lever were moved laterally. The signalman could not move the lever backwards and forwards without moving it laterally out of the recess. This movement effected the locking, but it did not move the point. It was like Mr. Saxby's catch rod, actuating everything

that ought to be actuated before the point-lever was moved. When it came out of the recess of the aperture it could be moved forwards, and would come opposite the other recess. Then it moved laterally again into that recess, and unlocked everything that ought to be unlocked, but not until the lever had finished its stroke, and had brought the point perfectly home; then it actuated the locking gear. In this way he had endeavoured, as he ventured to think, successfully to supply the two requirements to which he had referred. It had been said that it was advisable to have as few parts as possible. If when several levers should successively depend upon one another they were made to depend upon one only in order to have only one part governing them, that would be a mistake. The parts should not be too many, but it would not do to get rid of anything that was wanted, for the sake of having few parts. It did not much matter if the parts were numerous so long as they were simple and easily worked. Mr. Poole further stated, that in his invention the locking was maintained as follows:— There was a falling bar which came upon a notch on the sliding bar, and there was a pin upon the lever which raised the falling bar as it came between the jaws of the sliding bar. As it left those jaws the pin left the falling bar, which fell into the notch, and held the sliding bar immovable in its place, so that nothing could disturb it until the lever came back, and again had it in control.

Mr. W. L. Owen asked permission to bring before the members a locking apparatus (Fig. 5, p. 202), which he had brought out in 1866, on a system different from any described in the Paper. It fulfilled all the required conditions, inasmuch as it prevented the slightest movement of the signal levers before the switch lever was in the proper position. In designing the apparatus (which was intended to be as economical as possible) the idea of imparting motion to the locking bar by the signal levers or switch levers was thrown aside. Instead of one lever being made to act upon another by moving a lock by means of a more or less complicated mechanical contrivance, the levers in their movement simply rendered it possible or impossible, as the case might require, for the switchman to slide by hand a locking bolt, alternately locking and unlocking the necessary levers. The several levers, which were similar in character to ordinary ground levers, worked side by side in segmental frames of similar ordinary construction, and were provided with segmental tail-pieces (forged solid with the levers) working through slots in the ends of the frames. These tail-pieces were made to the same curvature as the frames. The segmental frames were slotted transversely just in front of the levers, when

these were in the backward position, and a sliding bolt worked backwards and forwards through these slots, whereby it was made capable of alternately locking the one lever or set of levers in the one side of the frame when in backward position, while the other levers were free. As soon as the last-named lever or one of the set commenced to move, the segmental tail-piece covered the transverse slot, and prevented the sliding bolt being moved back, and so releasing the first-named lever. The apparatus was designed for small roadside stations. It was applicable to all cases, excepting at the most crowded or complicated junctions, and had been extensively used—at colliery sidings where no box was required; at sidings where no signalmen were kept, the gear being provided with padlock bars and padlocks to prevent interference by unauthorised persons; at facing points on single lines of railway, to

FIG. 5.



lock both the switches and the signals, where they could be readily worked from the same frame—a cheap arrangement, dispensing with long switch rods. Also as a temporary means of locking the signals and switches of cross-over roads, when put in for the purpose of working single line in short lengths during

repairs of bridges or other works. At ordinary junctions (where signal-boxes were required), the back locking was easily obtained by a simple arrangement of slots of different patterns cut in the rear end of the segmental tail-piece. This gear had been in operation since 1866, and possessed the following advantages:—It could be constructed and repaired by an ordinary smith, there being no fitter's work about it. It could be fixed in place by a platelayer. The lock was perfect. The levers could not commence to move until all conflicting levers were completely locked. There was great simplicity of construction combined with solidity in the lock. There being no side strain on the lock, the locking was very durable, the repairs being in practice simply "nil." When used as an outlying facing-point lock, no locking bars or detector bolts were required. To move the switches the signal must first be put to danger, the lock be slid over, and the switch lever pulled, all these operations having to be gone through within a few feet of the facing point and of the moving train. To extend its use to longer distances the form of the frame had since been altered. The locking bolts, instead of being put in front of the bars, were placed behind; and the frames were made more upright, and the lever of greater length. The number of moving parts in the apparatus was small. Independently of the levers themselves there was only one moving part for an ordinary roadside station; and for a double junction there were only two moving parts. It might be objected that the operations here described were tedious, and took up time. It was found in practice that this was not so: the signalmen worked the hand-moved locks quite readily, even after being accustomed to those to which the necessary movement was imparted by the levers. The time taken in moving the locks was almost inappreciable; and as a rule the switchmen, knowing what train to expect, had the locks in readiness for the operations about to be gone through with the lever. A further modification of the apparatus had been adopted for the purpose of locking outlying facing points on single lines. A bar was provided in the frame, interlocking with the sliding bolt, and in substitution of the signal lever and segment. This bar was either connected direct on to the signal wire, or worked (by means of double control wires) by an interlocked lever in the main frame at the station. This arrangement was adopted, as it had been found that, in all ordinary wire or bolt locks, owing to the necessary slack in the apparatus, and the play between the end of the locking rod and the sliding bar, the switches could be partially opened while the signal was down;

and the friction of these parts had a tendency to prevent the return of the signal to the danger position, when the signal lever was thrown over for that purpose. These objections did not exist in the form of gear now described: the switch lever could not be moved in the least until the signal was at danger, and whatever strain there might be on the switches, none was transmitted to the locking bar. In this form the gear had been extensively applied to interlock the facing points in connection with such of the signals as controlled trains approaching such points from the facing direction; the cost was but little in excess of ordinary levers in similar situations without the interlocking. When thus used it became simply a cheapened and improved form (in connection with the signals) of switch indicator, giving to an approaching engine-driver ample notice as to the position of the switches, which was not the case with ordinary indicators.

Mr. C. H. Gregory, Past-President, said, without desiring to enter into those questions which it might be thought had already been sufficiently discussed, he wished to suggest one addition to the history given by Mr. Rapier, viz., that the detonating fog signal was first introduced by Mr. E. A. Cowper, M. Inst. C.E., somewhere about 1841 or 1842, and that in a report dated the 14th of April, 1844, General Pasley, the Inspector-General of Railways at the time, recommended it as worthy of general adoption. The Paper under discussion must have cost the Author a large amount of careful research, and it was a valuable addition to the records of the Institution, containing as it did so complete a history of the most important changes in railway signals. Never having patented the application of the semaphore as a railway signal, or derived any benefit from it, he could not but be pleased that in this, the first complete history of signals, the fact should have been recorded that he introduced the semaphore signal, now of almost universal use on railways, and that he had taken what had been described as "an important step" in interlocking signals. From 1840 to 1845 Mr. Gregory was engaged as resident engineer on the Croydon railway, and was actively employed in the mechanical details of railway working. During that time mechanical inventions were introduced by very slow degrees, and while the period of the first introduction of the semaphore was correctly fixed at the end of 1841, or the beginning of 1842, and its use was soon extended from the Croydon railway to the Brighton and the South-Eastern railways, it was some time before it was adopted into general use. The Brighton railway was opened from Croydon to Hayward's Heath in 1841, but it was not till the summer of

1844 that a double semaphore with signal locking apparatus was put up at the Brighton Junction, a few months after the erection of the Bricklayers' Arms Junction signals. The arrangements at the Brighton Junction, as well as at the Greenwich and Croydon Junctions, were at first of the simplest character. A signalman with two flags by day and hand-lamps by night worked the whole of the traffic, which, as far as the Greenwich Junction was concerned, was a very large one. In order to show that such simplicity of working was not only adopted by railway companies but met with the approval of the Government authorities of the day, he quoted a short extract from the Report of Sir Frederick Smith relating to the opening of the Brighton railway, dated July 10, 1841:—"The points of junction with the Croydon and Greenwich lines are also matters of some anxiety; for, unlike the ordinary junction of other railways, these occur where there are no stations, and consequently the safety of the traveller depends mainly on the switchman at each place.

"It is to be borne in mind that, until the new station at London Bridge is formed, and the additional line of rails laid, the engines of the three companies will work on the same rails from the London terminus to the Greenwich Junction. Great vigilance will therefore be required at this junction; and it is desirable to impress upon the directors of the Greenwich Company the paramount necessity of always placing at this important point a policeman of well-established character for strict obedience of orders, steadiness, promptitude, and presence of mind, since at this junction, owing to the frequent passing of the Greenwich trains, and to the circumstance of the Croydon and Brighton trains having to cross both the up and the down lines, it will be chiefly on this servant that the safety of the passengers will depend.

"My present duty, however, is with the Brighton line; and it behoves the managers of this railway to make their engine-drivers and conductors fully sensible of the necessity of the strictest obedience being paid to all signals, and of their approaching the two junctions at such a moderate rate of speed as to admit of their having the trains completely under command."

The selection of good men and good administration were considered the best safeguard rather than the introduction of new mechanical appliances. To show the correctness of Sir Frederick Smith's judgment, it might be stated that for a long period from 150 to 200 trains per day passed the Greenwich Junction without the slightest accident.

As another illustration of the fact that in those days the personal

qualifications of the men were looked upon as the best security for safety, he read an extract from General Pasley's Report, dated 14th March, 1843,[1] on the extension of the Eastern Counties railway from Brentwood to Colchester :—" In fact, I have the greatest confidence in the skill and judgment both of Mr. Braithwaite, the engineer-in-chief, and Mr. Hall, the manager, upon whom these details will depend, as I have seen no railway where the arrangements by signals, policemen, &c., for insuring the safety of passengers, are more perfect; and I know, by the declaration both of the directors and officers of the company, as well as from the men themselves, that their enginemen and firemen give perfect satisfaction to their employers, and are contented with the treatment they receive; and on inquiry I found that the number of miles which they drive during the week is very moderate, which is an essential point, not only for the comfort of this important class of men, but for the public safety, which depends upon their not being overworked."

In a Report dated 17th March, 1843,[2] on the projected Peterborough branch of the London and Birmingham railway, in reference to the proposed level crossings on single lines of rails that had been objected to as dangerous to the public safety, the General said :—" In order to judge how far level crossings may be dangerous to the public safety, I have repeatedly passed along the Northern and Eastern railway, from Stratford to Bishop Stortford, which may be considered as a prototype of the Blisworth and Peterborough branch, as it ascends first the valley of the River Lea, then that of the River Stort, in the same manner that the latter will descend the valley of the River Nen; and in consequence of this advantage, the Northern and Eastern railway has been completed with very little labour in earthwork, but it abounds in level crossings, there being no less than 19 or 20 in the space of 28 miles, at all of which, except private or occupation roads, gates have been erected, shutting across the road, and only opened for passengers when required, at which period they are shut across the railway. This is done by a gate-keeper living in a cottage on the spot. The trains of the Northern and Eastern railway never slacken their speed on passing those points, unless the gates should be shut across the railway, which are sufficiently conspicuous by day, and rendered so by a red lamp at night, which is a signal to

[1] "Report of the Officers of the Railway Department for the year 1843." Appendix III. p. 150, folio. London, 1844.

[2] Ibid. p. 154.

stop. This railway has been opened, though not to the whole of its present extent, for about two years and a half, and no accident has ever occurred at any of its numerous level crossings. The example of this line is, therefore, a sufficient proof that level crossings on a railway are perfectly safe, if steady gate-keepers be employed at all those of turnpike, or other public roads; and the management of the Birmingham railway is so very perfect, and all the enginemen, policemen, and others in their employment so competent and correct in the execution of their duty, that I see no danger whatever in allowing them to have as many level crossings as they please in the proposed line between Blisworth and Peterborough, which will not be more numerous in proportion than on the Northern and Eastern railway; for the number will be about 28 in 47 miles, of which the greater part are little frequented, whilst at the crossings of the most important public roads it is proposed to have stations where the trains will stop."

These indications of the spirit of the day, to depend upon men more than upon machinery, were confirmed by a circumstance which occurred shortly after he became resident engineer of the Croydon railway. He then made a tour of most of the railways opened in England, fired with the spirit of mechanical improvement and with the desire to reduce railway rules to a code. The Liverpool and Manchester railway was very well managed, and he asked the manager of that line to let him have a copy of their general rules and regulations. He was informed that they had none, but that they put good men in every place, and took care to keep them up to their duty. As a last illustration, he mentioned that in looking through the Reports of the Board of Trade on railways opened from 1841 to 1845, he found that any reference to signals was quite exceptional.

Admitting that the increase of traffic, and still more the irregularity attendant on its working, had induced the necessity for mechanical appliances, it was to be considered how far those appliances were necessary. There were, no doubt, many railways on which, without a complicated system, the traffic could not be worked at all; but there were some cases in which he could not help thinking that these systems of interlocking switches and signals, and other mechanical appliances might be carried too far, when it was considered what might be the result of the loss of a pin or a bolt, or the slacking of a rod, and the danger of men trusting implicitly to contrivances which were not infallible, and so depending less on their own caution and vigilance. He had investigated the circumstances attending one of the worst

railway accidents which had ever occurred in this country, and had come to the conclusion that it was caused by the sudden failure of a special signal which might perhaps have been dispensed with.

Mr. J. Dixon said he was not engaged in the management of railways, nor was he connected with the manufacture of signals; therefore he did not propose to describe the merits of any special patent. The conclusion at which the Author of the Paper seemed to have arrived was, that by a judicious use of the various inventions and arrangements placed within their reach by "signal" engineers, the use by railway engineers of facing points was rendered not only safe but also feasible. It was an axiom, that to run twice over the same ground necessarily involved an increased expenditure of wear and tear. Any one who saw the shunting of a long train must be convinced that the stopping of that heavy mass of material could only be achieved at a great expenditure, which had to be repeated in the back shunt. Between Askern and London many of the slow trains had to be shunted and passed from ten to twenty times by the quicker ones, which must add materially to the average cost and wear and tear on the journey. Again, it was clear that ten minutes' obstruction to a line added a largely-increased amount of risk. If therefore facing points and crossings could be used with impunity, a great advantage in the management and facility for economical working of railways would be gained. On the London and North-Western, at the Watford Tunnel, each train on the same line of rails was practically out of sight before the succeeding train came into view. If that was so, a large amount of rail was practically unused. And why should it be? Why should not the engineers, managers, and manufacturers of this machinery be able to devise such precautions, that each pair of rails might be more thoroughly utilised? That facing points could be used with impunity no one could doubt. No accident had ever occurred with Saxby and Farmer's lock, and that was certainly in favour of what he had adduced. If another illustration were wanted, it might be found in the fact that on the London and North-Western for twenty years the passenger traffic out of Euston was worked by attaching an extra engine. Arrived at the top of the bank, the extra engine slipped her couplings, and rushed forward in advance into a blind siding; the signalman there, trusting alone to his sure eye and steady hand, turned over the points with such success and regularity, that during the whole of the twenty years no accident occurred. It might, however, be satisfactory to know that since the Willesden Junction had been

opened all the trains stopped there, and the engine was detached. Captain Tyler was decidedly adverse to facing points, and regarded them probably with some degree of prejudice; but though Captain Tyler's Report for last year showed that a few accidents might have occurred at facing points, there were a large number of cases in which it was probable that accidents might have been avoided if facing points had existed. The complications of the signal and interlocking arrangements were not likely to promote the use of facing points. Moreover he feared that signal manufacturers had an idea that £25 a handle was the price to charge for a locking frame, and for trade purposes increased the numbers. To make one handle do the work of five was a step in the right direction. In illustration of this state of complication, he might mention that an eminent Engineer went, about two months since, to a station not far from London to examine the points and signal apparatus. The superintendent attended and explained the working, and showed how long a time it would occupy for a train to pass through, which, for argument's sake, might be taken to be five minutes. He further explained that on busy days they frequently had ten, fifteen, or even twenty trains in an hour. On its being remarked to him that this would seem to be impracticable, if each train required five minutes to be worked through, the reply was given, "Oh, sir, on them days we pulls out all this gear."

Mr. Robert Burn wished to refer to a point which as yet had not received much attention, namely, fog signalling. He was afraid that mechanics were at a discount, for an explosive signal had been spoken of as the best fog signal. He believed the only mechanical apparatus yet devised was that used on the North London railway, where a lower duplicate arm was fixed to the signal-post so as to come within easy range of the engine-driver's vision, and to enable him in foggy weather to be sure about the signal. This expedient was, however, limited in its application. The Author had spoken of audible signals, and had given a drawing of Mr. Anderson's audible signal on the North British railway. The great fault when an audible signal was fixed to a distance signal was that the gong or the whistle was always sounding. Practical men said this was an objection, because in large stations and complicated junctions the whistles constantly sounding would be a perfect nuisance to every one connected with the railway, especially to the drivers themselves. On one of the large railways running into London there was a standing rule that the drivers were not to whistle even in passing through junctions; if the signals were set for them to go forward

they must do so without whistling. To gain experience he had travelled on an engine on a foggy night. The head lights shining upon the fog in front, produced an effect very much like that of running into a white blanket; no object or landmark could be seen. This must tend to bewilder even the most experienced engine-driver, who if he happened to miss the distance signal, might be in a station before he expected it. Cases had occurred where fogs had formed very suddenly, and a train coming up before the fog men were out, serious consequences had resulted from the driver not seeing the signals. If the semaphore signals could not be seen, it naturally followed that some signal should be devised which could be heard; and this was the plan which in an elementary form had been acted upon for the last twenty years—detonating signals had been laid down. He believed that some mechanical contrivance might be introduced to free platelayers from standing out day and night in foggy weather to lay down these detonating signals, as it often proved, at some risk to themselves; and that an audible signal, not always sounding, but which could be made to sound when it was desired, would prove the best substitute. Such an appliance was required to perfect and complete the block system. An experiment which he had been carrying out at Epsom promised to end in this direction. A small gear was erected under the signal-box, by means of which the signal could be worked in fine weather just as at present; there was also a supplementary lever, to pay out a little more wire, and raise a treadle by the side of the line some yards in advance of the distance signal above the level of the rail, to bring it into contact with a trigger on the engine suitably provided and connected with the whistle. In foggy weather, if the signalman wished to give the driver an audible signal, he turned over a small supplementary handle, which at once apprised the driver that the signals were against him. The same results could be obtained by utilising a portion only of the stroke of the ordinary lever for working the signal blade, and the remaining portion for working the treadle. The engine attachment was of the simplest description, merely consisting of a rocking shaft, extending across the engine, suspended by two brackets, with a vibrating trigger on each end, and a small vertical lever keyed on to one end of the same shaft, from which a cord was led through guarded pulleys to the handle of the alarm whistle. The Author said the idea had occurred to him that it might be made an affirmative signal, and it was very clear it might; that when a driver approached a station in a thick fog he was not to go on unless the treadle was raised and the

whistle sounded. He hoped that the plan described, or some modification of it, when further inquired into, would commend itself to the members, and that the present cumbrous and somewhat expensive system of fog signalmen might be superseded.

Mr. Richard Johnson said he regretted that mention of the Midland railway was nearly left out of the Paper. Not only had the London and North-Western and the Great Northern, but the Midland Company had, for some years past, paid considerable attention to the important question of providing for the safe working of the increased traffic. For the last thirteen or fourteen years he had been almost every day carefully considering this question of locking apparatus or no locking apparatus. Fifteen or sixteen years since, almost every set of switches in a station was at liberty to be moved by any man who happened to be working in that station either as shunter or porter; and as the traffic day by day increased so did the difficulties in carrying on the increased work. He repeated that for thirteen or fourteen years he had carefully considered this question of working railways, and especially the working of large stations and the safety of junctions through which trains had to pass at high speed; and perhaps no one present had been more afflicted by those gentlemen who schemed these appliances than himself. He had, as far as he could, opposed the introduction of locking apparatus, but it was now only fair to admit, that, in his opinion, every set of switches which communicated in any way with the main line should be under the control of a signalman, and that it should be out of the power of any shunter or porter to alter those switches at will. It therefore came to this, that, more or less, locking apparatus was a necessity. He believed, judiciously applied, locking apparatus saved time, and he was sure it saved men in stations, and so far as he could see, it contributed materially to the safety of the working of the line. Signal engineers erred in this direction, that their machinery was too complicated; if they would turn their attention rather more to simplicity it would be well for them, and it would certainly be well for the Companies. One gentleman spoke strongly in favour of facing points for shunting trains. His experience was the fewer facing points the better. He did not like shunting to any great extent, but it was preferable that a train of thirty or forty wagons should be shunted safely rather than that there should be an excess of facing switches. There were shunting sidings at all large railway stations, and if facing switches were introduced as the means of getting into those sidings, many elements of danger would arise which did not at

present exist. He confessed that the number of levers in a box sometimes frightened him. Mr. Rapier had shown a locking frame which he had prepared for the level crossing at Lincoln with eighty-one levers. Mr. Johnson tried very hard to cut it down to sixty, but seeing that this was to govern a level crossing of two railways, many connections on each side of that level crossing, and also the various connections in Lincoln station communicating with the main line, he believed the number had been reduced to a minimum. Then as to the system of block working, he was not sure that the Paper fairly brought that question before the Institution. Most railways were now worked on what was called the absolute or positive block system. There were, no doubt, varieties of opinion as to the manner in which the block absolute was carried out. His opinion was, that it was not quite sufficiently absolute, and that at no distant date, the question should be thoroughly discussed at the Institution. There was so much tendency to crowd on the traffic that he feared railway companies were rapidly approaching a permissive block instead of adhering to an absolute block system. He thought that two trains should not be allowed to be between two block stations. It might be answered that that was the state of things now, but he believed he was correct in saying, that immediately a train had passed—say station B—the practice was to admit a train from A, although the train, which had just passed B might not be moving. He contended that, not only ought that mile and a half, or whatever it might be, to be kept clear, but before the driver started the train from station A he ought to know the state of things at B. If a train was standing there he should approach B with great caution, if not, a collision, some day or other, was inevitable. He thought there was something to be done by way of improvement in that part of railway working at the present day. It was known that third lines were being constructed as rapidly as possible for dealing with the greatly increased traffic on nearly all large railways.

Mr. Spagnoletti remarked that the Paper was an interesting history of the introduction and progress of railway signals. It showed the improvements that had been introduced, advancing from a simple lamp on a post up to a locking apparatus; how signalmen could be educated for their work; and how the large amount of traffic now conveyed on railways was carried by the agency of mechanical appliances. The marvellous increase of railway traffic, and the amount of the earnings of railways for the past ten years, were a proof of how much had been gained by mechanical and electrical assistance in working them; and how the carrying

capacity of the lines had been stretched and expanded by appliances of this kind; and, at a comparatively small outlay, with such great results. Had not these appliances been used, the only alternative would have been to have doubled the railways. The expense of this would doubtless have been much more than that of the original construction of the lines, from the advanced prices, which the railways themselves had caused, of land, materials, and labour. This he thought was a strong argument in favour of such appliances, and that, had they not been adopted, the dividends of the companies and the present price of their stock would be considerably less than they were now. Seeing that mechanical appliances had done so much in these respects, he considered that any brought forward possessing desirable improvements deserved a fair trial. Prejudice, generally found to be the want of a better knowledge and comprehension of any object or thing, was an awkward and difficult barrier to get over; but had not experience of past inventions (some of which were now admitted to be quite necessary) shown how long it took to introduce and get existing ones into use? The system of working railways in the present day, from the varied and later developed classes of traffic, was very different from that of the time when the accommodation of the lines was adequate to the demand then made upon them, and he could easily understand how those who had not closely followed step by step the recent improvements should feel doubtful as to their results; but experience should give confidence. Early impressions were always the strongest, and therefore he thought their conclusions were only natural, although perhaps not well founded. Mr. Rapier had pointed out the great advantage arising from sectional lines being laid down parallel with the main line. This would be found advantageous in the working of railways. Trains frequently had to pass each other on the great lines, and fast trains would perhaps overtake several slow trains in the course of their journey. There were many places where perhaps these lines might be constructed on land already held by the company, and the expense would not therefore be so great as if the whole of the land had to be purchased; and by means of the block telegraph these portions of line would simply represent junctions with branch lines. It was true that facing points would in such a system be rather freely introduced; but if these were worked with the locking bar, or the signalmen's cabins were placed so that they could get a good view of them, he did not think much, if any, danger would result from their introduction. If, however, they were considered by any company dangerous, then trailing points could

be laid, and the trains could back into these lines. The only delay experienced would be the time of shunting back, and there would be the advantage of being able to proceed as soon as the work at a station had been accomplished, instead of waiting for fast or through trains to pass; which waiting added to the delay and irregularity and to the troubles and dangers of working a railway.

With regard to the block telegraph, expressions had been used to show that, although it was generally employed, it introduced an element of danger; inasmuch as drivers, knowing that they were working under the block system, and getting an all-right signal to start, concluded at once that the line was clear right away to the next station; but without it, as their lives were endangered if anything should happen, they would keep a better look-out. But drivers knew, and no men better, that there were other causes for them to look out ahead than the fact of running into a previous train; because in all cases when trains broke down, it was a rule that the guard went back to stop the train following. The drivers also knew this, and it might be said equally as well to be a system likely to render them more inattentive than they otherwise would be without it. The other causes, such as platelayers being at work with a trolly on the line, or having a metal up, level crossings, cattle or carts passing, or anything having fallen off the previous train, or an accident to a train coming in the opposite direction—all these things were likely to occur, and because his own life was in jeopardy the driver would be careful in all cases to keep a good look-out to see that the line was clear, whether the block telegraph was there or not. With regard to audible signals, he believed they might be used with advantage in the case of a fog, or in a snowstorm, a hailstorm or a heavy downfall of rain, when the men would naturally shelter themselves behind the weather-board. This might be carried out by an electrical arrangement with a bell on the engine, which when set ringing would not stop until the driver stopped it by pressing a knob down; and a spring attached to the engine to rub over a piece of bent iron rail as the train was passing. Placing these pieces of iron rail on a railway 200 or 300 yards from every signal, the attention of the driver would be called to the fact that he was coming to a signal. This would be useful at all times, for even in fine weather he might be engaged in looking at his engine, and perhaps run closer to a signal than he should do, especially down an incline, before he was aware of it. Mr. Spagnoletti then proceeded to describe his fixed signals worked by electricity, they being in size the same as the ordinary semaphore signals now in use on railways, thus getting rid of

wires, which had to be strained to work the signals. He also stated he could lock signals and points, and signals and signals together by this electric signal, as was now done, by simply making contacts, and thus remove all the complicated machinery now used, which had been so much complained of. He also showed his arrangement for indicating in a signalman's cabin when the lamp of a distant signal was in or out, when it could not be seen by the signalman working it; and likewise his signal repeater, which showed the signalman the position of the same when the signal was placed out of his sight. With reference to intermediate stations on lines, he said that on the Great Western, the distance between some stations being 5, 6, or 8 miles, it was found necessary to have intermediate boxes; but with the electrical signal, as only instant contact was required to work it, and as it could be worked equally well at any distance, it could be worked automatically by the pressure of the engine on the rail, and thus save the expense of building huts and appointing men simply to act as repeaters of the signals sent to them.

Mr. Rowe, with reference to the locking gear exhibited, said no doubt, with the purse of the London and North-Western, the Midland, the Great Northern, or other large companies, expensive signals were all very well; but he happened to represent two small lines belonging to landowners, where they had not the advantage of such a command of money, and so these elaborate descriptions of locking gear were altogether out of the question. The junction expenses cost £700 for 12 miles of single line. On another little line there were three local stations, and it cost £500 for locking gear before the Board of Trade would allow the line to be opened. He found, what with the friction and the length of the rods, and one thing or another, this locking gear was continually getting out of order, and he was bound to confess, in some cases it was necessary to take out the lock and temporarily work without it. He believed the catch-rod system of Messrs. Saxby and Farmer, Mr. Easterbrook, and others was the right thing, as there was no strain upon the gear. It was all in the man's hand; he had only a certain power in the grip of his fingers, and could not strain the locking gear. No doubt a little more simplicity in the working parts was desirable. With reference to Mr. Spagnoletti's electrical arrangement, he of course could not claim the mercurial lamp as an original invention. Mr. Rowe happened to be connected with it some years ago, in working out the patents of Messrs. Whitaker and Jones, when it was found that the mercury, being so volatile, could not be depended upon.

The vibration of a passing train would sometimes cause it to indicate that the light was out when it was not; it would break contact in fact, and ring the bell. An endeavour had been made to overcome this by using a compound metal bar, which made and broke contact by heat and cold, but the difficulty then was to maintain perfect insulation, as the electricity was continually running to earth; the least speck of dust getting into the connections upset the whole thing. At last he gave up electricity, and succeeded in making the distance lamp relight itself, by applying the unfailing power of the compound bar to actuate a locking rod, which if the lamp ceased to burn or go nearly out, allowed the oil chamber to fly round, and light up another wick by means of ordinary matches. Now matches could be dispensed with, and a lamp could be kept burning any length of time; as the oil chamber in turning round would keep lifting and re-trimming the wick. He was bound to say, from his experience of electricity, that without the aid of a strong staff of electricians, and of gentlemen such as Mr. Spagnoletti to keep them going, he should not like to rely upon it.

Mr. Austin Chambers said the Author of the Paper had given him credit for being the first inventor of locking, but had connected Colonel Yolland's name with it. Now the facts were these: In October 1859, when the Hampstead Junction line was finished, Colonel Yolland told the North London company that he did not consider the Kentish Town station safe without some means of preventing the signalman from making a mistake. Messrs. Stevens and Sons, having the signal work in hand, undertook to so arrange the signals, and the opening of the line was postponed for that purpose. In the following month Colonel Yolland again inspected the junction, when the stirrups that worked the signals had been so arranged that the act of putting down one stirrup disengaged the stirrup that held the other. Colonel Yolland put his foot in the two stirrups at the same time, and thus lowered both the 'Up main' and the 'Up branch' signals, when he refused to pass the line. Being appealed to for information as to how the object could be attained, Colonel Yolland replied, "It is not my province to suggest, but to approve." Having ascertained what was required, that the facing points must be set for the main line before the 'Up main' line signal could be given, and that the 'Up main' line and the 'Up branch' signal could not be given at the same time, he by the end of December 1859 had fitted up the Kentish Town and Willesden Junction entirely to Colonel Yolland's satisfaction; and he might

add that the same locking, which almost amounted to the approved system of the present day, had been working ever since, was now in good working order, and had never been repaired. During the inspection Colonel Yolland made this remark to the Manager, "You see I have not asked for more than could be done, as one of your own staff has provided it; you will some day thank me." The same day he received from the General Manager, in the name of the company, a cheque for £50 to patent the locking arrangement. A few weeks after the patent was offered to Messrs. Stevens and Sons for the sum of £100, but that offer was refused.

The difficulty of keeping locking apparatus in order had been referred to. He had had charge of the signals for the past six months on the Metropolitan railway, where, he believed, the trains were more numerous than anywhere else, and at Moorgate Street Station, with 60 levers in one box, there had never been occasion to repair them in any way. It had been suggested that on busy days the locking was taken out. He could safely say that on a busy day that could not be done, as it would take two or three days to take them out. He therefore thought that more had been made of the difficulty of locking than there was any occasion for. He did, however, find fault with the way in which signal work was generally done. Sufficient care was not given to the quality of the material and the class of workmanship used; and a great deal of the difficulty with the signals was not in the locking, but in the rods themselves. There were two or three causes for this inferior workmanship creeping in. First, from letting the same class of work do for a point rod of 300 or 400 feet long, as for a rod of 3 or 4 feet long; also the rise in the extent of signal work was so sudden that the expense was looked at. Formerly, in the construction of a line, the cost of the signal was almost unnoticeable. About ten years ago the Engineer of the Great Eastern railway told him that if a junction with locking apparatus were to cost £400 or £500 they would be few and far between. This referred to a junction with 10 or 11 signals and 5 or 6 pairs of points. Another cause was the hurried way in which signal work was generally put up. As a rule, it could not be commenced until the other work was finished. It was often done in a great hurry. The Engineer was so anxious to get the line finished, and the signal work complete, that he overlooked quality of work; and the manufacturer and his men would generally condescend to overlook it, from the same cause. It was a common practice, when ordering sleepers and timber for railway work, to specify the quality, and whether creosote was to be employed or not; but it

was a very uncommon thing to have the horsings, to which was fastened the crank which held the facing point, creosoted. Again, when iron was ordered for bridge work it was generally specified to bear so many pounds per square inch; but when rods were ordered to work points, it was unusual to specify what they were to be or what they were to bear. Again, when plate or bar iron was ordered, some particular brand was named; but when wire was ordered for signal work this was not always the case. Price generally ruled. The locking was so small an item, and gave so little trouble compared with the outside work, that he should like to see more attention paid to it; and then he was quite certain that, instead of the complication of signals being, as it was called by some, a drawback, they would have great security with very little trouble.

Mr. Allport said the object of the discussion seemed to be to bring before the Institution the various patents for working locking apparatus and signals. Some of the remarks had surprised him, and he feared the tendency of the present day was so to increase the complications of these things, whether by electricity or by sound, that it would be almost impracticable to work railways, unless a stop was put to the introduction of many of these inventions. He understood there were ninety existing patents, and was sorry to hear the number was likely to be still further increased. With regard to the block system, the Midland railway was, if not the first, certainly one of the first to introduce it, nine or ten years since, on their main line. He did not approve of some of the observations as to the system of blocking between stations. In the case suggested, the distance signal at B ought to be a sufficient protection between A and B. He could not sufficiently impress upon those in charge of railways the importance of disciplining the drivers in attending to signals, because he contended that the block system, or any other system, ought not to supersede the necessity of the engine-man attending to the signals. Whether a train was running in foggy or in fine weather, an experienced engine-driver knew pretty well where he was; he knew when he approached a signal, and that a distance signal ought to stop him. There was a general feeling amongst engine-drivers that they need not look out, as other people were taking care of them; and the more this was the case the less care would they take of themselves. He contended that a perfect block system should be maintained, and that when a train had once passed the home signal at B, the signalman should keep his distant signal up until he knew that the train was beyond

reach of a second train approaching. That rule should be rigorously observed on all lines, and it ought to be sufficient to secure safety. It had been said that facing points were very desirable, so as to allow a slow train to get out of the way of a fast train, but he would never have a facing point into a siding if it could possibly be avoided. With the block system properly worked there ought to be ample time for any train to shunt from the main line into a siding in the usual way by the back shunt, without the danger of facing points. He objected to the introduction of third lines for short distances, because the additional junctions and facing points must necessarily increase the danger. No doubt the locking apparatus was a great improvement upon the old system; but it was a fallacy to suppose that it would altogether prevent accidents. This was exemplified at Syston Junction, where, for twenty-three years, with the old system, there had never been an accident; but under the new system, introduced at that junction three years ago, one of the most serious accidents took place that had occurred upon the Midland for some considerable time. That accident happened simply because the man was some distance off, and could not see the point under his control. He thought it would be dangerous to depend upon electricity for working the block system at intermediate points, with stations 5 miles apart and a crowded traffic; and that it would be far better to block the whole 5 miles.

Mr. FINDLAY, manager of the London and North-Western Railway Company, stated that the block system had been adopted on about 800 miles of the 1,630 miles of opened line belonging to that company, and that it was to be extended to the whole of the main line, including also the arrangements for the interlocking of the points and signals in terms of a promise made to the Board of Trade, in common with others of the leading railway companies. Many of the officers of the company held the permissive system, which was first adopted on the London and North-Western railway more than twenty years ago, to be a good one. There were 135 miles now worked according to that system. The company employed 40,000 men, 16,000 of whom were specially engaged in working the traffic. There were 1,600 engine-drivers and 2,000 signalmen; and on their selection and training safety largely depended. The block system on such lines as the London and North-Western meant more sidings, more men, more signals (and he was not prepared to say that an increase in the number of signals was always an addition to safety), and to a great extent a reconstruction of the accommodation works at the principal stations.

Curiously enough, the system had developed a class of accidents not known before. It was impossible to secure perfect safety under any system; probably the block system, which was more expensive and complicated than the one it superseded, interfered too much with the personal responsibility of the drivers and the signalmen. The engine-drivers of the fast and express trains had, in a memorial to the directors, expressed their doubt as to the additional safety of the system. Certainly many modifications and improvements would be required before it attained anything like perfection. The qualifications now required on the part of signalmen were greater than ever; they must know something of mechanics, understand telegraphy, and be able to read and write.[1] In addition to the 2,000 men actually employed, an extra staff of signalmen to the extent of 10 per cent., to fill up vacancies occa-

[1] Memorandum as to Practice adopted by the London and North-Western Railway with regard to the Training and Relief of Signalmen:—

(1.) No man is allowed to take up regular duty as a signalman until he has had at least a fortnight's training at the post for which he is intended, his pay during that time being passed as extra.

In cases where men require a longer training owing to the difficult nature of the duties, or from other causes, the fortnight is extended, frequently to as much as six weeks, under the authority of the Chief Traffic Manager.

(2.) At the expiration of the training period, and before the man takes up duty, the Superintendent of the district must forward to the Chief Traffic Manager a form, signed by himself, certifying the man as to—

(1.) A knowledge of telegraphy.
(2.) The working of semaphore and other signals.
(3.) The company's rules.
(4.) Reading and writing.
(5.) Sight and capacity for judging distance.
(6.) Ability of distinguishing colours.

(3.) For the purpose of relieving the men on Sundays and during meal hours, and of providing for cases of sickness, the company employ a staff of about 10 per cent. extra signalmen, who are termed "porter pointsmen," and who when not employed in these duties are utilised on the platforms. Practically, however, it is found that the men are almost entirely occupied in relieving the various signal posts—when so engaged they are allowed the same pay as the men they are relieving, and when sent away from home they are allowed expenses in addition.

(4.) In addition to the appointment of the porter pointsmen, at the smaller stations, one or more of the porters are trained as signalmen—so as to relieve the men at the boxes during meal hours and on Sundays.

(5.) At the most important posts the signalmen are relieved every eight hours, at less important posts, every ten hours; and at stations where the duties are not particularly onerous, every twelve hours.

sioned by sickness and other emergencies, was regularly engaged. No man was allowed to take regular duty as a signalman until he had had at least a fortnight's training at the post for which he was intended, and the time was often extended in special cases to six weeks. A certificate was also required from the superintendent of the district stating that the man had a knowledge of telegraphing, of working semaphore and other signals, of the company's rules, and of reading and writing, the capacity of judging of distances, and the ability to distinguish colours. At the most important posts the signalmen were relieved every eight hours, at less important posts every ten hours, and at stations where the duties were not particularly onerous, every twelve hours. There was an accident and a provident society among the men for relief in case of sickness or death. It was managed by the men themselves, and the company contributed to its funds £3,000 or £4,000 a year. The interest which the men took in their work was remarkable. Not long since a foreman at Bolton had his shoulder dislocated, and was taken home and ordered to be kept quiet. Towards seven o'clock the next evening—he was accustomed to night duty—he said to his wife, "Eh! lass, aw canno' stay here; they canno' get on without me; aw mun go yonder;" and he dressed himself and went to his accustomed post; but had not been there an hour before he was knocked down and lost his leg in the performance of his duty. No soldier in the battle-field showed greater courage or self-sacrifice than some of these men, and he wished to bear the highest testimony to the good conduct and discipline of all the servants acting under him, and to railway servants generally. Signal-boxes of all sizes had been erected. One at Edgehill, near Liverpool, had eighty-four levers. It was desirable to avoid such large constructions whenever it was practicable. That at Edgehill could not be worked without announcing the arrival of the trains by telegraph. In working telegraphic gongs were more to be relied upon than the mechanical gongs first introduced. The mode of working in fogs and snowstorms had received great attention. Fog-signalmen were appointed to repeat the signals, and the company had an arrangement by which the station-masters and traffic inspectors obtained the names and addresses of the platelayers and other persons connected with the line who had posts assigned to them for the performance of that duty. Each man was provided with a great-coat; and if he was on duty more than six hours, he received refreshment. In case of fog or snowstorm the engine-driver had to pull up at the signal, and ascertain personally that the line was clear. The following were extracts from the official

circular of instructions to station-masters and others in the case of fogs and snowstorms:—

"Station-masters must arrange with the traffic inspectors to have the names and addresses of the platelayers recorded at their stations, and must come to an understanding with the ganger of the district as to the positions on the line which are to be occupied by the respective platelayers in case of fogs or snowstorms, coming on by day or at night, and also as to their relief at proper intervals should the fog or snowstorm continue.

"If the fogmen are out more than six hours, arrangements must be made for furnishing them with the needful refreshments.

"On a fog or snowstorm coming on suddenly, and the fogmen not having taken up their positions, enginemen are instructed to stop at the main signal cabin and ascertain whether the section in advance is clear.

"*During foggy weather or snowstorms, when a train or engine has stopped at a station, or is shunting into a siding under the protection of the main and distant signal, the signal 'line clear' must not be sent to the block station in the rear until the train or engine has proceeded on its journey, or has shunted into a siding clear of the main line.*

"During frosts or sudden changes of temperature, men in charge of points and signals will be held responsible for having them examined by the platelayers or ganger to see that they work correctly, and that the expansion or contraction of the rods and wires has been properly adjusted by means of the regulator; and in addition to this, it will be the duty of the signalmen, when going off and coming on duty, to ascertain that the points, signal lamps, and arms are working correctly in accordance with the movements of the levers.

"Care must be taken after heavy falls of snow to examine the working of the exposed portions of the apparatus in connection with the signal posts, in order to see that no obstruction has been caused by the accumulation of snow, so as to prevent the proper action of the arms and lamps.

"During snowstorms the platelayer who is employed to repeat the distant signal must look to this; but if no fogman is employed, the ganger on duty must do so while the snow, or its effect, continues."

From the large increase that had taken place in the traffic of the railways generally, it would be impossible now to work the lines on the old time system. He admitted that the block telegraph and the interlocking of points and signals were a necessity under the present conditions of the traffic, but under the pressure that had

been brought to bear by public opinion, both had been adopted too hastily, and both were in his opinion capable of improvement and simplification.

Mr. Francis Fox, of the Bristol and Exeter railway, remarked, that although he represented a line of small length and traffic compared with the London and North-Western railway, yet on it ran the fastest trains in England, and probably in the world, and it was worked throughout on the absolute block system. The valuable and admirably illustrated Paper would assist Engineers of railways in the selection of suitable interlocking apparatus, without which the sanction of the Board of Trade could not now be obtained to the opening of a new line, or of a connection with an existing passenger line. Messrs. Saxby and Farmer generally performed their work in a most efficient manner, being well aware of the requirements of the Board of Trade, and understanding the subject of interlocking thoroughly, which had now become quite a science. Mr. Poole's apparatus appeared to be a feasible mode of effecting what was accomplished by the catch-rod system, and it was under trial on the Bristol and Exeter. He was surprised to find railway managers of high position and experience preferring to trust to a man's intelligence rather than to machinery. It was impossible, in his opinion, for intelligence alone to meet the requirements of the present day without the aid of machinery. He advocated the combination of the two, by the adoption of efficient machinery under the control of intelligent signalmen. It would not be possible to work large stations with safety without a concentration and interlocking of signals. The great value of the interlocking system was that it rendered it exceedingly difficult for a man to produce an accident by a temporary loss of self-possession, to which the most intelligent signalmen were liable. Some of the requirements, however, of the Board of Trade he thought carried the system too far, and rendered it very difficult to work the traffic; but the inspectors were generally willing to relax the requirements when shown to be productive of serious inconvenience. The interlocking system had also the merit of economy, it being obviously more economical to employ concentrated effort than effort distributed over a larger area. The old-fashioned disc and cross-bar were still in use on the Bristol and Exeter. They had the advantage of being more readily seen from a distance and of being always positive in their indications, giving no negative signal whatever. The semaphore had certain obvious advantages, such as that of placing signals on the same post for trains in different directions. He did not at all approve of "caution" signals.

They were indefinite and led in practice to various degrees of speed; but there could be no misapprehension of the meaning of "danger" and "all right" signals. He had invented an arrangement by which the disc and cross-bar were pivoted on one bar; and instead of turning round horizontally, they merely turned a quarter of a circle. They were found easier to work at distances of half to three-quarters of a mile. He approved of the regulations which compelled an engine-driver to pull up at the distant signal, and proceed cautiously to the home signal. He agreed in the objection to facing points; they were at best but disagreeable necessities, and should be avoided wherever it was possible. There were several difficulties that had not yet been overcome in the working of facing points by the interlocking apparatus, such as the expansion of the rods, and the necessity for accurate fitting in the bolts of facing-point locks, as the slightest error in fitting might lead to a serious accident. Greater simplicity in the apparatus was still most desirable. The absolute block system was introduced partially on the Bristol and Exeter line in 1861, and entirely throughout the line and branches in 1866 and 1867, no permissive block system being in use. Special regulations were adopted for working single lines. The system was strongly objected to by the then traffic officers of the railway, as being likely to lead to obstruction to the traffic; but it was now approved by all the officials, and was found to facilitate greatly the punctual working of the line. Formerly on that line, and probably on many other lines, a sort of "hit and miss" system was often adopted in the starting of the trains; but now every irregularity was booked. The adoption of the block system had prevented the recurrence of a class of accidents to which they were previously liable, viz., that of collisions between trains following each other on the same line. The signal huts were 2 miles or $2\frac{1}{2}$ miles apart from each other, but in some cases the distances were much shorter. Great care was taken in the selection and training of the men; for the block system, if worked at all, should be worked thoroughly well. The system was also found useful in other ways, such as in enabling the signalman to send forward an intimation of the loss of a tail-lamp to a train and the like. He did not approve of the automatic electric block system, preferring that the control of the signalling apparatus should rest with an intelligent signalman. No shunting was allowed to take place on the Bristol and Exeter line, at stations through which trains passed without stopping, within five minutes of the advertised time of passing. The station-master had to enter the time at

which each train ought to pass, and the time at which it actually passed, and had to sign his name as a witness of the fact. Many serious accidents might, in his opinion, be prevented by the general adoption of such a regulation. There were between twenty and thirty trains daily each way on the Bristol and Exeter line; but on portions of the line the trains were more numerous. In certain cases where a siding occurred between two ordinary block stations, rather than run any risk, an additional hut had been erected, and the junction of the siding had been worked as a block station.

Mr. SIEMENS said it was now generally conceded that the block and interlocking systems were conducive to the safety and development of railway traffic. Nothing could exceed the ingenuity displayed in the contrivances exhibited; but he observed that the electric telegraph was left out of the interlocking arrangements which had been brought forward. It was used only as an auxiliary to signal trains from station to station, but it formed no part of the interlocking system. In Germany and Belgium an interlocking system had been adopted lately with most satisfactory results, in which the three elements of the switch, the optical signal, and the telegraphic signal were combined into an automatic system; so that it was impossible for a train to leave a station, for the optical signal to be raised for its departure, and for the switch to be put right, until the telegraphic signal had arrived from the next station to say that the line was clear. He thought that no interlocking block system could be looked upon as safe and complete unless it combined the three elements alluded to; and he was strongly of opinion that a block system, if adopted at all, should be made absolute and complete, and not permissive, as had been advocated in the course of the discussion.

Mr. FOX, through the Secretary, desired to add the following remarks by way of explanation:—He did not wish to be understood as objecting to automatic electric signalling, if used in conjunction with the employment of intelligent signalmen. In illustration of this statement he might mention that he was introducing electric repeaters for distant signals, to show in the signal-hut during foggy weather the actual position of the disc and crossbar signal, whether at "all right," at "danger," or (owing to the expansion or contraction of the signal-wire) in an intermediate position. He was also adopting an electric indicator for the points of self-acting switches situated at the end of loop-lines on single branch lines, too far from the signal-hut to be safely actuated by point connections, and which consequently opened with the passage of the train

from the main line to the branch, and closed for the trains from the branch to the main line. If from any cause the switch-point should not fall quite close to the stock rail, electric contact was broken, and a bell was set ringing in the hut, giving notice of the fact to the signalman, who would thereupon put on and keep the up-branch signals at "danger," until the defect had been remedied. Referring to the cases of sidings joining the main line at places situated between ordinary block stations, it appeared to him that as at all important sidings a man was usually stationed, the proper course was to convert the junction of the sidings into a block station and work it as such. On the Bristol and Exeter railway where sidings situated intermediately between block stations joined one line only, the whole section of that line was blocked, until the train doing work at such siding had passed into the succeeding section. In order to insure that two trains should not be in one section at the same time, starting signals worked in connection with the block system were fixed at the forward end of every block station, and the rule was stringently enforced that "line clear" should not be given from box B to box A until the whole of the train had passed beyond the starting signal into the section B to C, or had been shunted into a siding; and a white target at the tail of every train enabled the signalman (as well as the platelayers and others) to see that the entire train had passed. Allusion had been made to the danger of giving "line clear" from B, at a junction with a branch line, to A on the main line and to C on the branch, at the same time, and that under such circumstances the ordinary signals were the only protection against a collision at the junction. This difficulty was met on the Bristol and Exeter railway by a positive rule that all branch trains should stop before entering the main line and before leaving the main line for the branch.

Mr. W. H. Preece said he had been for many years engaged in the application of electricity to the working of traffic upon railways, and could therefore speak from some experience. Twenty-one years ago he was employed by Mr. Edwin Clark in carrying out what was now known as the Permissive System, and eleven years ago he presented to the Institution a Paper[1] which performed to electric signals at that period the same function which Mr. Rapier's Paper had now performed to fixed signals. The working of railway traffic was fast becoming a science, and a science based, as all sciences should be based, on experience and

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxii., pp. 167–192.

observation. It was a pure example of the doctrine of "evolution," and the principle of the "survival of the fittest" was well illustrated in many of the systems illustrated in the diagrams. Each railway company had been working upon its own experience; and now the joint experience of the whole was being welded and moulded into general practice, and the result was shown in improved working. Statistics did not justify the general outcry against railway management. If the deaths that occurred in factories, or in the streets of London, were published by the press with the zeal that railway accidents were now made known, public attention would soon be diverted from its crusade against railway management. Railway managers and officials had acquired by experience a knowledge of the facts upon which the science could be based, but there was no literature of railway working to which others could refer. Data and authentic facts were required for those who were being educated for the future management of railways, and these were to be found not only in such papers as Mr. Rapier's, but in the reports of the inspecting officers of the Board of Trade. The object of the Paper appeared to be to show that the two great requirements in railway working were uniformity and simplicity. Uniformity was not yet obtained, for the same signals were used for different purposes, instead of being employed for the same purpose. Thus the semaphore when used as a home signal meant "stop;" as a distant signal, "Stop, but go on." The disc on one line meant "danger," on another line "safety." It must not be forgotten that simplicity meant comprehension. What was incomprehensible and apparently complicated to one mind might be simplicity itself to another mind. A signalman, confined in a cabin with nothing else to do but to work and watch a lever, must have a very dull comprehension if he did not thoroughly and speedily master what appeared to an occasional visitor the most complicated array of levers and switches. The importance of the introduction of repeaters had scarcely been dwelt upon sufficiently. Formerly the position of distant signals was fixed with the sole object of keeping them within sight of the signalmen; but the introduction of repeating signals had provided the means of fixing them so as to consider alone the attention of the driver. The effect of slack wires and the numerous causes which interfered with the due exhibition of the signal were compensated for, and the greatest confidence was given to the signalman in the working of the signals. The block system, as an abstract principle, simply meant that trains should be kept apart by an interval of space instead of by an interval of time; but there were innumerable

methods of carrying that system into practice. The growth of the system had been slow, and, indeed, sudden changes were not desirable. Opportunities had been given to perfect the apparatus employed. But there were causes which interfered with its general introduction. On the South-Eastern line the system had been uninterruptedly in use for eighteen years; on the North-Eastern it was only just being introduced; on the North London it had been regularly worked for seventeen years; on the London and North-Western line it had only been introduced a few years. The slow progress of the system was perhaps, in a measure, due as much to prejudice as to ignorance. In a Committee of the House of Lords, recently appointed to inquire into the subject, a noble lord, the Chairman of a railway company, asked whether it was possible for little boys to play tricks with the block system, while two others endeavoured to show that the system was inapplicable upon a single line worked by a single engine! A railway official had also asserted that in such a case it would be an unmixed evil and a useless expense; and another said, that when the trains were a long way apart and were few in number the system was unnecessary. The fact was that in each of these cases the trains were kept apart by a space which was infinite. It was objected to the block system that it tended to impair the look-out of the driver, but this objection was as mythical as those adduced against the introduction of railways themselves. It was not to be supposed that when a driver received an "all clear" signal he buttoned up his coat, lit his pipe, and desired the stoker to tell him when they came near the next station. Drivers were as careful of their own lives as of those of the passengers under their charge, and there were many causes besides trains in front of them to occupy their careful watch. The historical "coo," broken rails, fallen signal-posts, detached goods, fouled lines, &c., would always remain to require their careful and incessant look-out. Moreover, practice and experience belied this objection. It was also suggested that the system increased the element of human fallibility by adding to the number of signalmen. Statistics had been given to show that the number of signalmen had been largely increased; but it had not been satisfactorily shown whether that increase was due to the introduction of the block system, or to the increase of the traffic. If the system were carried out in its entirety it would really lead to a diminution of the actual number of men employed at a given time, and it would materially lessen the anxiety and responsibility of keeping a look-out on the part of the signalman. Instead of confidence

being impaired by mechanical appliances, he thought they tended to inspire confidence. Machinery did not work of itself; it was not automatic; it did not supply a substitute for manual labour. It introduced delay, but it could not favour accident; it reduced the liability to error, and had the advantage of never sleeping or tiring. It was objected that the block system did not afford perfect security; but its advocates had never contended that it did. Like other machinery, it was to some extent dependent upon the skill and attention of those who worked it. Care and attention were more than ever required on the part of those who worked it, but it involved less visual watchfulness. Bells and telegraphs supplied certain information, and freed the signalmen from the uncertain exercise of their eyes. All instruments were, however, dependent on human action, discretion, and judgment; and as long as drivers would run past signals, pointsmen pull over the wrong levers, not all the results of experience, the dictates of reason, the inventions of genius, or the skill of the engineer would prevent accident. The true working of the block system was essentially a question of discipline, and its proper maintenance was the result of supervision. The system had the advantage of affording freedom from anxiety. Some years ago the general manager of a railway company, after a series of accidents, had a bell placed in his house, and gave instructions that it was to be pulled day or night whenever an accident took place. At the same time he introduced the block system upon the line, and from that day to this the bell had never been rung. It avoided confusion of mind. The signalman in his box had nothing to do but to fix his attention upon the apparatus before him, and was in no danger of being distracted. There were, no doubt, some defects in the working of the block system upon various lines; but the system itself ought not to be made the scapegoat for the defects of the agents employed in carrying it out. Thus on some lines the objectionable practice was in use of blocking the line before the train was allowed to start, instead of the more natural method of blocking the line behind the train. The necessary result of this pernicious practice was frequently to secure two trains in one section at one time, and thereby to produce accident; and this must occasionally happen, on the doctrine of probabilities, on those lines which continued that practice. It compelled the true exhibition of signals, and thereby remedied one of the greatest causes of reckless driving. It increased the capacity of lines for the conveyance of traffic, as was indisputably shown in the cases of the North London and the Metropolitan railways, and it unquestionably expedited the

conveyance of that traffic. By preparing the way for the passage of trains it stopped the nuisance of continuous and useless whistling. It had been stated that the permissive system was still employed to some extent on the London and North-Western line. That system was not introduced for the sake of safety so much as with a view of increasing the capacity of the line. The block system, to be properly worked, should be worked on the same principle as a distant signal. The speaking telegraph in connection with block signals he regarded as an unmixed evil. Its introduction was based on the assumed fallibility of the electric signals; but electric signals gave the least trouble, and worked the best of all the mechanical appliances on railways. Old modes of telegraphing were now giving way to improved systems, based upon the number of beats upon a bell and upon variations in sound. He thought the bell communication between cabin and cabin answered all the purposes which were supposed to be fulfilled by speaking telegraphs. It had been objected that six beats upon the bell indicated one thing, and three beats repeated twice indicated another, and that errors might arise from this identity in the number of beats. There was, however, as much distinction between the two signals as between the words "president" and "secretary." He could see no reason why the block system should not be made compulsory. Where the traffic was light it could be easily carried out with existing apparatus; and as the traffic increased the company had the means of bearing the additional expense. When the system was once introduced upon the main line, there was no difficulty in establishing it upon the branches; and unless the railway companies voluntarily adopted the system, Parliament, as the exponent of public opinion, would probably force them to do so.

Mr. Johnson explained, by the aid of diagrams, the mode of working the block system on certain lines, and expressed his belief that the method generally adopted was an approximation to the permissive block system. He objected to giving "line clear" at a station until a preceding train had started from the station in advance. He also objected to giving "line clear" at a junction for two trains at the same moment.

Mr. W. H. Barlow said that the faulty details in the carrying out of the block system formed no good ground of objection against the system itself. He believed the system to be a good one; but he did not think that it would remove the inconvenience and danger attending the working of mixed traffic, the only cure for which would be the laying down of separate lines for fast and slow trains, which would give additional safety, and greater capability as to the amount

of traffic. The block system could be readily applied to lines like the Metropolitan and others in the south, where the great bulk of the traffic consisted of consecutive trains on the same line, having no departure from the line except at stations; but it was very different in the north, where at almost every mile there was a branch or a siding. One great difficulty was to secure attention in foggy weather. The system at present adopted, of calling in the temporary aid of plate-layers, labourers, and porters to place exploding signals on the rails, was a rough expedient, defective in itself and unworthy of the age. The signal should be given on to the engine itself, and not placed upon the line. When mail-bags could be taken into and be delivered from the Post-office vans while running at high speeds, it was obvious that the simple matter of moving a signal placed on the engine was easy to accomplish; and its effect would be to obviate all those accidents which arose from drivers running past signals without seeing them. A diminution of speed would remove one of the great sources of accidents. When trains ran at thirty miles an hour, drivers were ordered to slacken speed to ten miles an hour in passing junctions and important stations. At this speed a man with a hand-lamp or a flag sufficed for safety. The present speed of forty miles an hour requires trains to be run through junctions and stations at speed. He did not deny the advantages of interlocking; but experience showed that, with all the elaborate contrivances and large expenditure in signal arrangements, the accidents were as numerous. That result he attributed to excessive speed over junctions and through stations, to the mixture of trains running at different speeds on the same lines of rails, and to the present imperfect system of signalling during fogs.

Mr. R. Price Williams said the history of the rise and progress of signalling as given in the Paper was exceedingly interesting, more especially as it showed, in a striking manner, that the improvements were but the natural consequence of the remarkable development of the railway traffic in this country. In the days when trains were few and the speed comparatively slow, the simple expedients alluded to for signalling trains were probably sufficient. When, however, the intervals between trains came to be measured by minutes instead of by hours, then those simple expedients could no longer be relied upon, and so by gradual steps the semaphore signal and the block system were arrived at. He considered that nothing short of a distinct space interval, with the additional provision, alluded to by Mr. Johnson, of a caution signal communicated to the station immediately in the rear of the blocked portion

of the line would effectually provide for the safe working of the traffic. In confirmation of these views, he might mention that the jury in the case of the Euxton accident had just recommended that such a caution signal should in future be given.

The advantage resulting from the interlocking of points and signals had been questioned by Mr. Allport. However, as a practical mechanic, familiar with the construction and working of various interlocking systems, Mr. Price Williams considered that, with good workmanship and the use of sound and well-selected materials, which should alone be employed for such critical work, he saw nothing to warrant their not being most implicitly relied upon. In fact, he would as soon distrust the working of the complex machinery of a locomotive as that of the present admirable interlocking apparatus, within at least such reasonable distances as 800 yards. The effect of the alterations of temperature upon the long switch rods, which had been the chief obstacle in the way of their safe use, had now been surmounted by the simple expedient of the compensating bar. The beneficial results which had followed the introduction of the system of interlocking points and signals had been described by Mr. Fox. No greater contrast, perhaps, could be afforded than in the case of a roadside station Mr. Price Williams had recently had occasion to revisit after a long interval. There, instead of the point-lever handles—which he had remembered in former years scattered about the place, a stumbling-block and offence to all who unfortunately came in contact with them, and at the mercy of any one who, impelled either by malice or want of thought, chose to meddle with them—he found the switches all connected up to and worked from a raised signal-hut which commanded a complete view of the station and far beyond. No one, he thought, could fail to recognise in this case—which ten years ago was the ordinary type of a roadside station—the removal of a real source of danger in railway working. The Cannon Street Station signals might be mentioned as another striking instance of the beneficial results arising from the adoption of the interlocking system. Passing in and out of that station, as he had done during the last eight years, on an average twice a day, he could testify to the most perfect working of the system, under circumstances as difficult and complicated as it was possible to conceive; with a double junction at one end of a viaduct, and at the other one of the largest and busiest stations in the kingdom, with its multitudinous arrival and departure platform sidings, cross-over and through roads, &c., all controlled and worked from the signal-hut on the viaduct, and worked with the most perfect ease and safety.

He had frequently had an opportunity of carefully examining the mechanical arrangements of those signals, and could bear testimony to the great simplicity of their working. He had noticed as many as four trains passing at the same time under the Cannon Street signal-box, and some of them traversing right across from the lines at one end of the viaduct to the arrival sidings at the other end of the station, and yet, to his knowledge, not one single accident had occurred there in the period referred to.

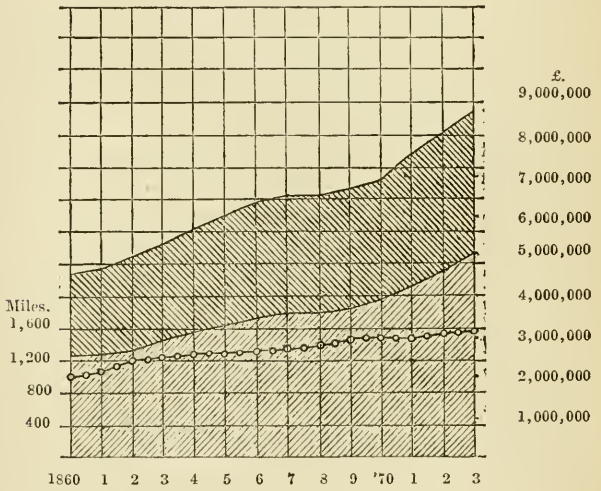
The question, however, to which he more particularly wished to draw attention was, how far the block system, with all the concurrent advantages of the interlocking of signals and points, was capable of meeting the future requirements of the constantly increasing traffic on the principal main lines of railway. In order more clearly to explain his views on the subject, he had placed upon the walls, with the permission of Mr. Oakley, a diagram (Plate 32), which was a graphic representation, or chart, of the working time-table of that portion of the Great Northern railway between London and Peterborough. It showed the times of departure from London, and the times of arrival at Peterborough and the intermediate stations during each four and twenty hours. He should explain that the thick black and the thin blue lines represented the coal trains and the slow goods trains respectively, the thick blue lines the fast goods, the light red the ordinary passenger, and the thick red lines the express passenger trains. It would not fail to be observed, that the express passenger trains intersected the slow trains at a number of points between London and Peterborough. Without the agency of the block system, it would be impossible for the necessary shunting of the slow traffic to be carried on with the freedom from risk of accident which characterised the working of the traffic on that line. A glance at the diagram sufficiently showed that already a good account was there given of the time during the four and twenty hours; and it was a question worthy of consideration how far, even with the aid of a really perfect block system, provision could be made for the future development of traffic. His belief was that if the time had not already arrived, it would soon do so, when, having regard to the rapid rate at which railway traffic was increasing, the fast and slow traffic on the principal main lines must of necessity be separated.

In illustration of the rate at which railway traffic was increasing, he might mention that the gross receipts in England and Wales had increased in the ten years, 1861 to 1871, from £24,021,928 to £41,383,065, or rather more than $5\frac{1}{2}$ per cent. per annum, a rate at which the entire traffic would double itself in every thirteen

years. Figs. 6, 7, and 8 showed the receipts from passenger and goods traffic on three principal English railways, viz.: the London and North-Western, the Midland, and the Great Northern. The rate of increase of the passenger and goods traffic on the London and North-Western had averaged a little over 5 per cent. per

Fig. 6.

London and North-Western Railway.



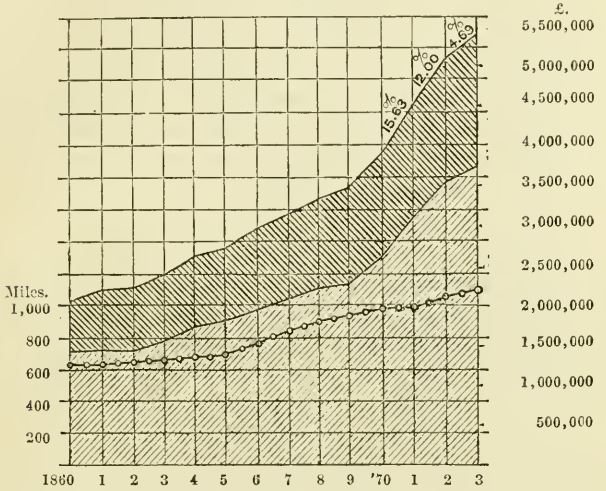
The light shading represents Goods, the dark Passenger traffic.
The average annual rate of increase of the total traffic is 5 per cent.
The chain line represents miles of line open.

annum during the last thirteen years. This, however, scarcely gave a fair idea of the amount of the increase. He might, however, state that in that time the number of passengers had increased from 18,000,000 to 31,000,000, or at an average annual rate of increase of about 8 per cent.; in other words, the passenger traffic was doubling itself in every nine years. On the Midland and the Great Northern railways the increase of the traffic receipts was still more remarkable, averaging, in both cases, fully $7\frac{1}{2}$ per cent. per annum; rates of increase which, if maintained, would double the traffic in ten years, and quadruple it in twenty years. It might be urged that in this increase of traffic no account was taken of the concurrent increase of the mileage of new lines opened during the period in question. That, however, had, he considered, very little bearing upon the question, since those extensions were of the character of small tributaries, which served but to add to the volume of the traffic upon the main lines. Timely provision,

therefore, should, he thought, be made for this natural growth of traffic. From what had been said, it appeared that already the

FIG. 7.

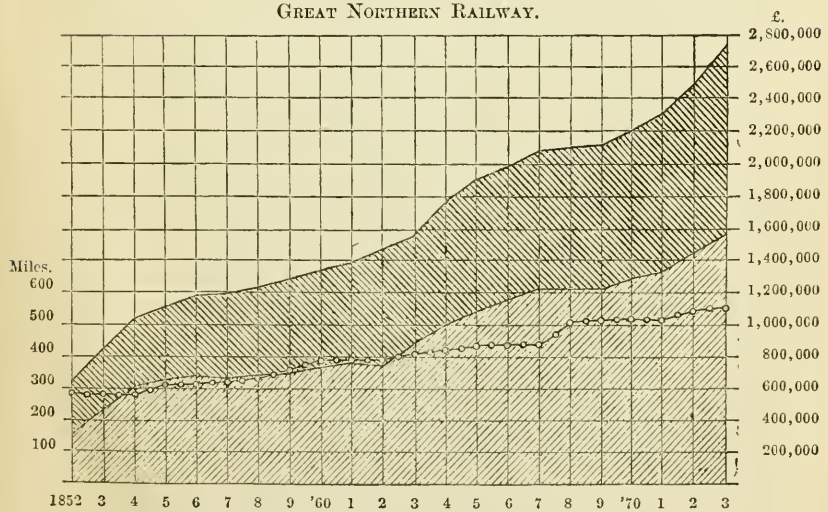
MIDLAND RAILWAY.



The light shading represents Goods, the dark Passenger traffic.
The average annual rate of increase of the total traffic is 7·74 per cent.
The chain line represents miles of line open.

FIG. 8.

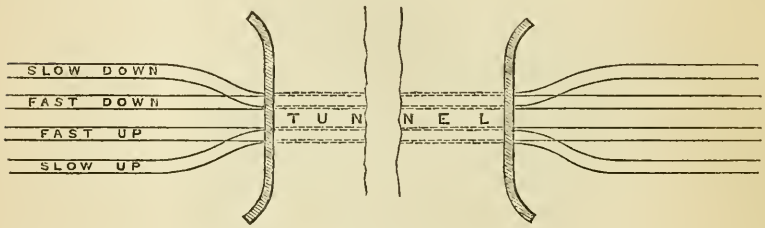
GREAT NORTHERN RAILWAY.



The light shading represents Goods, the dark Passenger traffic.
The average annual rate of increase of the total traffic is 7·49 per cent.
The chain line represents miles of line open.

Midland Company was taking steps to provide for the increase of traffic by the construction of long sidings; but these sidings involved either the use of facing points, or the alternative of trailing points, through which the trains would have to be shunted, involving much loss of time, to say nothing of the risk. Pending the quadrupling of the main lines to meet the growth of traffic, he thought some such plan as he had indicated in Fig. 9, might be used with advantage, as a means of avoiding the necessity for either facing or trailing points; the long sidings being con-

Fig. 9.



tinued side by side with the main lines through the tunnel. One great advantage would result from quadrupling the lines at the London end of the principal railways, and the consequent separation of the slow from the fast traffic, that would be the simplification of the working of the interlocking gear, and the removal of that tendency to complexity which had been so much objected to in connection with it, as directly the slow and the fast traffic were worked on separate lines each line would have its own separate system of signals and points.

A great deal had been said and written lately with regard to the increase of railway accidents. He thought the rapid increase of the traffic had not been sufficiently taken into account in considering this question, as it followed that, whilst the same or even greater precautions might be taken, the tendency to accident must necessarily increase in a far higher ratio than the direct increase of traffic.

He was glad to be able to confirm the statement of Mr. Chambers as to the share which Colonel Yolland had in the discovery and application of the interlocking principle. He remembered that in 1857, when the Welwyn Junction signals were being put up, Colonel Yolland laid great stress upon the necessity for connecting the signals and the levers; and the repeating signal adopted there was, he believed, Colonel Yolland's own suggestion. It was a

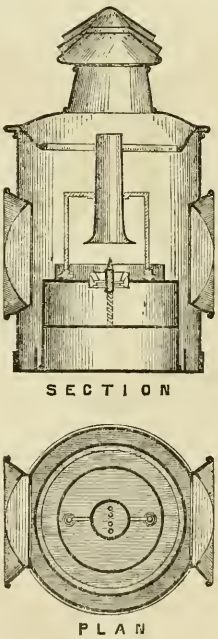
matter of regret that the distinguished officers of the Board of Trade, who might have greatly added to the interest of the discussion, were not present to state their views.

Mr. E. A. Cowper said he believed the method suggested by Mr. Price Williams for separating the two lines of rails by a few inches (although the trains ran over the same ground) was an excellent one for avoiding the necessity of facing points, and was adopted with good effect in the tunnels at Primrose Hill and Watford. He agreed that the commencement of interlocking dated from the time when Colonel Yolland and Mr. Gregory expressed their views on the subject, and he thought the complete interlocking system, insuring the safety of the signals and the switch apparatus, was largely due to Messrs. Saxby and Farmer. The apparatus as at present used, could not possibly give conflicting signals. As to facing points, with express trains running through them at forty miles an hour, in his opinion, they should only be used under exceptional circumstances. He thought something further was required in the way of communicating between the man on the road and the man on the engine in foggy weather, in addition to the fog signals which he had had the pleasure of introducing into the railway system. With respect to the calculation as to the cost of accidents, he hoped it would not be understood that the loss of life and misery produced by them were disregarded. He did not think shareholders would hesitate to sanction the small additional outlay of 0·5 per cent. for the sake of securing additional safety. But the best system would provide for the largest amount of traffic, and ought to be adopted, if only as a matter of economy. It was really a question whether there should be an increase in the number of signalmen, or a decrease in the number of the public. He was glad to hear the statement that some signalmen did not work more than ten, or, in some cases, eight, hours a day. He knew of cases in which they worked twelve hours, and when they left work they were often in a state of complete exhaustion. There could not be a better argument in favour of the block system than the diagram of the working time-table of the Great Northern railway between London and Peterborough (Plate 32); it was in fact simply an unanswerable argument for keeping the trains a certain distance apart.

Mr. Jas. N. Douglass said he understood it had been intended to include in the Paper a chapter on the subject of signal-lamps, but that this had been abandoned owing to the length of the communication. He greatly regretted this, as railway signal-lamps were still very inefficient. The present lamp (Fig. 10),

which should be an efficient guide to the engine-driver by night in all states of the atmosphere, with the exception of thick fog, was little better than the common stable lantern referred to as having been used on the Great Western about 1837. The light was inclosed in a tin box, and all that was utilised for the intended purpose was what issued from two holes, 4 to 5 inches diameter, the two beams of light being somewhat condensed

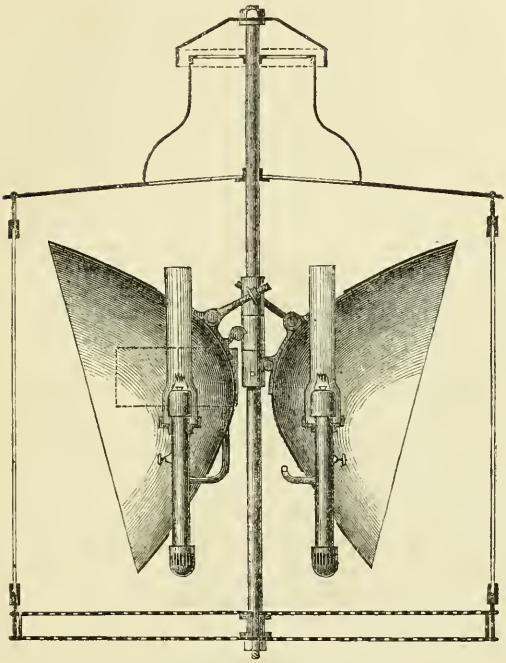
Fig. 10.



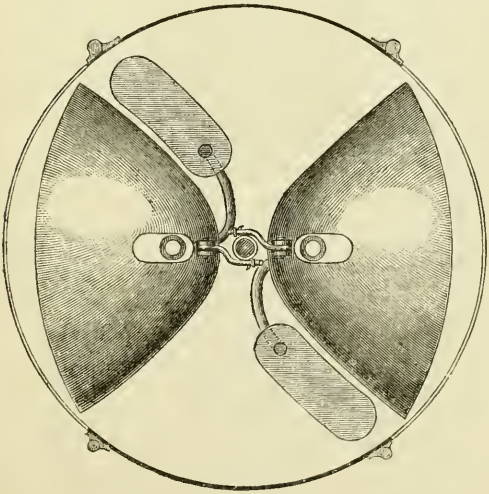
Present Railway Signal Lamp.
Scale 1 inch = 1 foot.

by a glass bullseye fitted in each hole. He had found by experiment, that the maximum power of each beam was only four times that of the unaided power of the burner; and when the red and green spectacles were applied, the maximum power of each coloured beam was only $1\frac{1}{2}$ time the unaided power of the burner. He had devised a lamp (Fig. 11), comprising a cylindrical box, provided with two burners and parabolic reflectors, in which nearly the whole of the light radiating from each burner was condensed into two beams of 18 to 20 degrees divergence. Each reflector was arranged for adjustment horizontally or vertically to

FIG. 11.



SECTION



PLAN

PROPOSED RAILWAY SIGNAL LAMP.

Scale 1 inch = 1 foot.

meet any curvature in the line or elevation of the signal-post. The maximum power of each beam from this lamp would be about 120 times that of the unaided power of each burner. Therefore, assuming that the burners consumed collectively the same quantity of oil as the present lamp, the relative efficiency of the proposed and the present lamps would be as 15 to 1. The cost of such a lamp as he had described would be from £10 to £12. If economy of oil were a matter of primary consideration, he would suggest a plan which had lately been adopted with success at some English lighthouses, that of having two powers for each burner; a single power sufficient for a clear atmosphere, and a double power for thick weather. His remarks as to the insufficiency of signal-lamps would also apply to the roof-lamps of railway carriages: with the present lamps no passenger could read with any degree of comfort, although more than sufficient oil was usually consumed for the purpose.

Mr. Oakley said, referring to the diagram (Plate 32) representing the working of the trains of the Great Northern line between London and Peterborough, that the block system was adopted, together with the "in-and-out" system of telegraphing, by which each station had two advices of the approach of a train before receiving the "be ready" signal of the block system. For instance, in starting a goods train, it would be telegraphed to eight or nine stations forward; and each station, as the train passed, took up the tale, and telegraphed to two or three stations beyond, so that it might be known when the train would arrive, and that the line might be cleared accordingly. When the train was at the last block station the "be ready" signal was given, to which the reply was returned, "come on," or "stop." In order to afford the necessary facilities, there were twenty-two separate shunting sidings on the down line, and about as many on the up line, besides two lengths of a third line 5 miles each. A working time-table was supplied to every station-master, driver, guard, and signalman, containing a list of the sidings, so that it was known where a train could be safely housed in case of accident or delay. The other sections of the line were worked in a similar way. With regard to the observations as to the necessity for additional lines, he could only say that he should be happy to undertake to provide for double the present traffic over the same road without any difficulty. As to facing points, they were like good dinners—the fewer one had of them the better. When the facing point was opened for the main line, and the train had not to impinge on the tongue, no limit was placed to speed; but if the tongue was closed a reduction of speed was

insisted on, since the point could not be so safe as the continuous rail, however well it might be locked. The method adopted on the North-Eastern line, at the suggestion of Mr. Harrison, the President, which method pinned the tongue at the extremity, appeared to him to be the nearest approach to safety. The point of the tongue was the weakest part, and it was to that that attention should be directed. With regard to signals at junctions, experience had shown that they ought not to be placed on one post. Each line should have a separate post, and the signal should be from 50 to 70 yards from the fouling point, so as to leave sufficient margin between the train and danger. It would, he thought, be found necessary to extend this practice to stations. These precautions were needed not so much to provide for a crowded state of the line as for an unusual or unexpected occurrence in the ordinary course of working. The training of signalmen was a matter of the greatest importance. They should be men of a peculiar class, who thought practically of nothing but signalling. A genius or an intelligent man might be wandering when he ought to be looking at his signal. With regard to fog signals, the regulations were printed and placed in every block box and at every station. The platelayers, who could not work in foggy weather, were told off to the different boxes when the fog began. It was the duty of the platelayer to go to the signal-post, and if he found the signal at danger to put down a fog signal, removing it only when the signal at the post was at safety. It was suggested that there should be a self-acting signal that could be put down immediately. Managers would be glad to consider any proposal in reference to that subject; but it should be remembered that to put down a fog signal at a signal post was, practically, to lessen the space between the signal and the station where the danger lay; for, ordinarily, a man saw a danger signal 300 or 500 yards before he approached it. That was the point to which attention should be directed—to provide something, say 1,500 yards from the station, which was simple, economical, and that could be depended on when used. It might be, as had been stated, that inventors were sometimes an infliction; but railways could only be successfully managed and developed by the combined efforts of the mechanic and the manager; and railway managers were under too many obligations to the inventive genius of their countrymen not to be grateful for it, and to desire that inventors would go forward in the same direction, in the full belief that they would find in railway managers ready acceptors of their methods.

Mr. J. G. Picking described, by means of a diagram, "Ager and Pickering's Improved means of Signalling on Railways" in foggy weather. To the side frame of an ordinary locomotive engine was attached a wrought-iron plate, extending downwards to within a few inches of the top of the rails, and also a few inches outside the metals. Near the bottom of this plate a small roller was fitted at a right angle, free, of course, to turn on its axis, and also to move vertically; in the latter case pushing up a small rod, which acting by cranks and levers, took direct hold of the spindles of the driver's whistle, and by means of a spring, locked it open, making it absolutely necessary that some act must be done on his part—the mere pressing of a button—to cause the whistle to cease sounding. Now, say 50 yards in advance of the distant signal was fixed either to the sleepers of the permanent way, or in brackets bolted to the rails, and free to turn on its lower and long axis, a steel yielding spring camber connected to the same wire and lever, or it could have a separate arrangement, working from the signal-cabin the ordinary arm or light. This bow, or camber, when vertical, had its crown slightly above the line of the bottom of the roller, fixed as described to the engine; but, as it was yielding, it never received a blow, however fast the train might pass over it, the only effect being to elevate (slightly) the roller, and open the whistle, &c., as described. This only happened when the semaphore, arm, or light was at "danger," and the driver was unable, from obscure or foggy weather, snowstorms, in tunnels, &c., to see a signal against him. Upon the whistle sounding he reversed the engine, applied the brakes; the guard was also aroused, and the impending accident was prevented. In the case of the permanent way being under repair, the superintendent had only to put one of these temporary cambers, say 100 yards on the advance side of the road under repair, and casualties to workmen would be prevented. The question of the cambers standing the speed of a fast train had been proved by the fact that they had been passed over by the engines of the London, Chatham, and Dover Railway, attached to their daily continental tidal trains now for three years, without the slightest appearance of injury.

Mr. Rapier, in reply, said, if any proof were needed that the signalling system was far from perfect, it would be found in the able observations made in the course of the discussion. The diagram (Plate 32) of the working time-table of the Great Northern railway was very valuable; and he might add that, but for the example set by Mr. Price Williams in connection with previous Papers, the present communication might not have been

illustrated so extensively as it had been. Mr. Douglass was right in saying that there was great room for improvement in signal lamps. His suggested improvement was not a mere theory, but had been found a practical necessity, notably on the Great Eastern railway, which was specially subject to fogs. Mr. Siemens's proposal had received more attention on the Continent than in England. At present, signalman B informed signalman A that a train had passed or had not passed; but the new idea was that signalman B locked up signalman A, so as to take it out of his power to signal any additional train forward. It had been urged by Mr. Johnson that at a junction the signal "line clear" ought not to be telegraphed back to both lines at the same time; while, on the other hand, Mr. Allport had expressed his preference for the plan which did not give the drivers too much information at once, and suggested that permission to leave a block station and approach a junction ought to be taken strictly as permission only as far as the distant signal, and that giving them too much warning was as bad as giving them too little, as that led to "nursing" the drivers. Both these views were the result of long practical experience, and formed one of many illustrations of how carefully all these things were considered by railway authorities, and how difficult it was to arrive at hard and fast lines on many points. With regard to audible signals, again, objection had been taken to "nursing" signalmen and drivers; but a foggy day was an exceptional period, when he thought some additional care ought to be taken. If a driver could not be signalled through the medium of the eye, signals might be used which should appeal to the ear. He thought it would be most objectionable to give an audible signal in all cases, but it was desirable to have the power of doing so in cases of fog. If it was desired sometimes to give an audible signal and sometimes not, a special mechanism must of course be adopted, and then it would be a question whether the advantage gained was sufficient to balance the inconvenience of having appliances whose use was to be only occasional, and which might, therefore, be out of order when their application was required. Mr. Barlow's pertinent question as to the case of a siding between two block stations raised a point that ought to be clearly understood. The block system was often blamed for faults not its own. Expression was frequently given in the newspapers to inconsistencies of this sort, "This accident happened in consequence of the block system; the home signals were at danger, but the distant signals were at safety." Now that was not the block system, and it was absurd to call it so. Similarly, if a siding

were interposed between two block stations, and could not be fully controlled by either, that was not the block system. The only safe way in such a case was to constitute the siding itself a block station. To this course it was objected that this would lead to a great multiplication of block stations. To meet this objection he could only urge, that it was now found necessary to guard every point of connection with the main rails, and if it were necessary to have the profit and advantage of more communications with the main rails, the expense of making them reasonably safe ought not to be feared. The danger arising from complication was certainly less with three block stations than with two block stations having a siding situated somewhere between them. It had been said, that on busy days at the times of fairs and races, the locking gear was often taken out and no harm done. But on very busy days, when there was a congestion of traffic, accidents rarely happened, because the trains were generally travelling at a slow speed at all stations or points of junction, and, in fact, were often within sight of one another; every driver knew that he was acting on his own responsibility, and went as far as he could see and no farther. Accidents more frequently happened from exceptional circumstances on ordinary days. To attempt to carry out the block system without the interlocking system was hardly fair to the unfortunate signalman who had to work it. With reference to the machinery adopted for this purpose, he could say that the railway managers had plenty of choice; there being now several very good machines for the purpose; but in almost all of them the inventors appeared to have overlooked the great axiom in mechanics that the great point to be attained in any contrivance was simplicity and fewness of parts. In many of the machines now in use there were from a dozen to fifty pieces of mechanism between the lever which locked and the lever locked by it. It was impossible for two levers to lock each other, and yet have independent motion, without the intervention of some part or parts, but if a lever was made to lock another by the intervention of only one piece between them, then the locking was performed undoubtedly by the least possible number of pieces. Further, if the same additional piece was made to do duty for several levers, such mechanism must as a natural consequence be very simple. It was with this view that he had contrived the locking apparatus which had been described, believing that the machine with the smallest number of parts would be found to be the most practical in use.

With regard to future expectations of traffic, and the probability of the railways being able to cope with it, by means of improved

systems of working, some conclusions might be arrived at by taking into consideration the changes that had taken place in the traffic in the streets of London. Fifteen or twenty years ago, when the traffic in the streets of London was far less than it was now, the delays were far greater. Now, at all important points of junction policemen were stationed to control and direct the traffic, and the drivers of all vehicles now understood that the signal of a policeman's uplifted hand was a stop signal which must be obeyed; and the result was that method and system were able to work a greatly increased street traffic, almost entirely free from those vexatious delays which used to take place. By comparison, the traffic of the railways at present with what it would be twenty years hence might be said to be as the traffic in the streets of a market town was to that of London. In his opinion the true solution of the problem would be found to lie in adopting that system of working which should make the railways capable of the greatest amount of dividend-paying work.

With regard to the question of speed, that had long since been settled; and it would be useless to attempt to go back to the old rate of speed. He ventured to say that, with a sufficiently long purse and a fair prospect of dividends, there were many engineers of experience who would not hesitate to make a railway for trains to travel at the rate of 100 miles an hour. There was no physical impossibility in the way; but it was a cardinal axiom of the profession that all outlay should be remunerative. He, therefore, had great hesitation about such proposals as doubling the lines, building additional viaducts, and erecting costly works. He thought that every cheap expedient should be exhausted before any such extravagant luxuries were indulged in. These might be obtained in the course of the next twenty or twenty-five years; but there would be still the necessary crossings for the transference of trains from one line to another, and new trouble would then arise in getting the fast and slow traffic across each other at stations and junctions. There was no panacea, no palladium, no Utopia, and they must, therefore, work, and work, and still work on.

Mr. Harrison, President, said he was sure all would unite in giving their best thanks to the Author for the valuable Paper and Diagrams he had contributed, which would be preserved in the Minutes of Proceedings, and be a valuable record of the rise and progress of railway signalling. With regard to speed, he was not in the slightest degree afraid of it. As a rule, express trains were the most punctual and the most safe. It was not that they ran faster, but that they stopped at fewer stations, and, carrying

fewer passengers, they were less liable to detention. With reference to the diagram exhibited by Mr. Price Williams (Plate 32), it was a most complete method of showing the day's work of a railway, and he had himself been accustomed to employ a similar plan for that purpose. When managers objected to the use of such diagrams, he could only conclude that they did not understand them. As to accidents, he believed it would be found that most of them, although perhaps occurring at different places, arose from very similar circumstances. A map, on the principle of a wreck chart, showing the accidents arising from year to year, and their positions, was a most useful help in investigating the causes, and would indicate that most accidents took place at junctions and at stations. Such a map would show the railway companies the special points to which attention should be paid. The question of facing points had been alluded to; and indeed there was nothing more urgently needed than a complete facing point, protected by wedges, or by any other mechanical contrivance which would enable trains to run over it at full speed. He believed the time was not far distant when that would be accomplished. He did not pretend to say what would be the best plan. He had successfully adopted for some years a plan of his own; but he was not prepared to say that it might not be greatly improved upon. He had so great a horror of facing points, knowing the accidents occurring at them, that on the line between York and Berwick, for many years, except at the stations at Darlington and at Newcastle, there were only three facing points in a distance of 160 miles; but the increase of traffic had of late necessitated the introduction of a few more. If a safe facing point were really attained, nothing would more facilitate the passage of a large amount of traffic over the lines. With regard to fog signals, no system he had seen could be said to be perfect; and as many accidents occurred during the foggy season, it was obvious that the question was one of the greatest importance. Not long since, on the Great Northern railway, during a dense fog for twenty-four hours, it was found necessary to stop the goods traffic over a portion of the line. In reference to the block system, he thought it had been lately forced upon the companies rather more rapidly than it was possible to provide efficient means to work it. In former times nearly all the pointsmen and signalmen were taken from the class of plate-layers, or guards, and they had a complete knowledge of the working of railways. But when a company was called upon to provide suddenly 500 or 1,000 men for signalling, it was impossible to find

the requisite number of properly qualified men. The situation—being shut up in a box eight hours continuously, and not to speak or be spoken to—was a most unpopular one; plate-layers would not willingly go, and the men engaged, though they might go through a month's training, could not be regarded as at once efficient. He did not say that time would not overcome the difficulty, but a special class of men would have to be trained for the work. Signalmen were liable to fall asleep, and the occurrence was not a rare one. He had known a dozen trains, stopped at different intervals because a signal could not be obtained from the station in advance. A fireman had to be sent on, perhaps a distance of 3 miles, and he found the signalman fast asleep. Again, a signalman, on awaking from his slumbers, might forget what train had passed, and give a wrong signal; and he might admit a train within the block when there was another train on the line. These things actually occurred, but were not necessarily brought before the public; and such errors, resulting from human fallibility, must be expected to give rise to a number of accidents. As to the cost of the block system, he felt sure that if a perfect system were brought before railway directors they would not hesitate to adopt it; but he thought the estimate of the Author fell considerably short of the mark, and that many things that added largely to the cost had not been taken into account. The suggestion of Mr. Douglass, with reference to lamps, was of considerable importance; for, as Engineer to the Trinity House, his attention had been for years devoted to the subject, and he had produced lamps of the greatest possible power. It had occurred to Mr. Harrison at the time that some modification of the Trinity House Lamp of the First Order, exhibited at Mr. Hawksley's Conversazione in 1873, might be adopted for railways, which would add alike to the comfort and the safety of the passengers.

At the meeting of March 31st it was specially resolved to adjourn for a fortnight, in order to avoid holding a meeting on the evening of Easter Tuesday, April 7.

April 14, 21, and 28, and May 5, 1874.

THOMAS E. HARRISON, President,

in the Chair.

The discussion upon the Paper, No. 1,393, on "The Fixed Signals of Railways," by Mr. Richard C. Rapier, occupied the whole of these evenings.

The following Candidates were balloted for and duly elected, on the 14th of April :—Thomas Ashbury, James Barr, William Batten, Charles Blackwell, Frank Samuel Braham, James Cleminson, William Langton Coke, Charles Henry Darbishire, Reader Harris, John William Drinkwater Harrison, Stud. Inst. C.E., Captain Edward Harvey, R.E., Leslie Craswellér Hill, Edward Jackson, John William Johnson, Sir Harcourt Vanden Bempde Johnstone, Bart., M.P., Thomas Edward Kemp, Louis Auguste de Jacques de Labastide, Charles Mark Palmer, M.P., Henry William Pearson, David Rankine, George Shortrede, Stud. Inst. C.E., Urban Armstrong Smith, John Stevenson, Gilbert Macleod Stewart, Arthur Thomas Walmisley, and Alexander Wilson, as Associates.

The following Candidates were balloted for and duly elected on the 5th of May :—Percy Burrell, Thomas Curtis Clarke, Charles William Hawkins, William King, and Henry Valpot Francis Valpy, as Members ; Thomas Hope Green Berrey, George Woulfe Brenan, John Richard Brittle, William Frederic Butler, Frank Cheesman, Stud. Inst. C.E., Henry Deane, B.A., Charles Preston Gibbons, Stud. Inst. C.E., Edward Worrell Jarvis, Thomas William Jeffcock, William Millbanke Mayes, John Charles Melliss, Edward Perrett, Joaquim Galdino Pimentel, Robert Sharland, Stud. Inst. C.E., Walter Halsted Cortis Stanford, Edward Herbert Stone, Stud. Inst. C.E., Archibald Sutter, and Henry Michell Whitley, as Associates.

It was also announced, on the 5th of May, that the Council, acting under the provisions of Sect. III., Cl. VII., of the Bye-Laws, had transferred Wilfrid Airy, B.A., Henry John Card Anderson, Marcus Smith, and Wilberforce Wilson from the class of Associate to that of Member. Also that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-laws, as Students of the Institution :—Lawford Maclean Acland, Percy Leonard Addison, Robert Philip Atkinson, Charles John Seymour Baker, Edward Baker, Alfred William Thomas Bean, Alexander Bewley, Percy Wilson Britton, William Henry Cole, George Owen William Dunn, Charles Henry Holme, Lawrence Moore Kortright, William Cuthbert Lewis, Edward Leycester, Charles Perrin, and the Hon. Lockhart Matthew St. Clair.

May 12, 1874.

GEORGE ROBERT STEPHENSON, Vice-President, in the Chair.

The following Candidates were balloted for and duly elected:—Roscoe Bocquet, George Bush, William Frederick Gooch, William Norman Swettenham, and Sir William Thomson, LL.D., F.R.S., as Members; John Ashworth, William Climie, Thomas Hillas Crampton, B.A., Samuel Cutler, William Boyd Fitzgerald, Stud. Inst. C.E., John Newman, Stud. Inst. C.E., Charles Ower, James William Smith, George Spencer, George Eastlake Thoms, William Topley, and Robert George Underdown, as Associates.

It was announced that the following Candidates, having been duly recommended, had been admitted by the Council, under the provisions of Sect. IV. of the Bye-Laws, as Students of the Institution:—George Vaughan Brown, James Brand Cree, and George Wood.

No. 1,384.—"Peat Fuel Machinery," by Joseph McCarthy Meadows.

The several systems of machinery for macerating and pressing peat, at present in use, can be conveniently divided into two classes, which, for distinction and brevity, may be called the wet process and the dry process.

The wet process comprises all methods for making dense turf, in which peat, in its natural condition, is macerated or mixed so as to form a pulp, either without, or with the addition of water.

The dry process includes the compression, by mechanical force, of peat in a dry, powdery condition, and is represented by the system of Exter for making compressed turf.

The Wet Process.

In the wet process the pugmill principle was first applied for tearing and mixing peat. It was introduced in Bavaria by Weber, within the last twenty years; and the modes of arranging the blades upon the upright shaft, and of forcing the peat pulp

from the mill under a moderate pressure, have been since that time the principal objects of improvement. In other respects, there has not been any material departure, in external form, from ordinary types of pugmill machinery.

Different arrangements of the blades and of the forcing or squeezing action have been introduced, and will be illustrated by reference to examples of the best modern German, Dutch, and English machinery for the wet process.

Of the German machines, that made by Schlickeysen offers one principle of construction. The mill is, in general, from 5 feet to 6 feet in height, with a diameter of about $2\frac{1}{2}$ feet at the top, slightly decreasing downwards. In this system the blades on the upright shaft are arranged as an irregular spiral, which combines a downward forcing or squeezing action with that of tearing and mixing the peat. The peat is thus not only made into pulp, but in that condition is forced outwards through holes or dies (usually from 3 to 4 inches square), in one or more mouth-pieces, at the sides near the bottom of the machine. As the pulp issues it is cut into short lengths, and removed on boards for drying.

In the Dutch machine by Rahder, the operations of tearing the peat and of forcing it from the mill are performed by distinct portions of the mechanism. The mill itself is about 6 feet in height and nearly 3 feet in diameter at the top. In the upper part of this machine the arms or blades on the upright shaft simply tear and mix the peat. The pulp thus made sinks to a chamber or space in the bottom of the mill, over which space the foot of the upright shaft is carried by an iron bridging piece. This lower chamber is, therefore, not occupied by the shaft; at the same time it is in open communication with the body of the mill except where it is crossed by the bridge-bar for carrying the shaft. In this chamber a short horizontal spiral or screw forces the peat pulp outwards, and in so doing subjects it to a mixing action. In this arrangement there is but one mouth-piece, placed 2 feet from the side of the machine, to which it is connected by a taper matching piece. The spiral or screw, therefore, constantly works against a mass of pulp which is being steadily moved, under pressure, through the taper matching piece, to the holes or dies in the mouth-piece. This spiral is from 2 feet to $2\frac{1}{2}$ feet in length, and about 1 foot in diameter.

In connection with the twofold action of the Dutch machine, a third mechanical arrangement may be adopted, in which, for a better comminution of the peat, the action of a horizontal screw or spiral is mainly relied on, in combination with fixed cutters in the

inside of the casing. The peat machine of Messrs. Clayton, of London, consists, in principle, essentially on these conditions.

The motive power is a portable steam engine, usually of from 6 to 8 HP. The principal Schlickeysen machine and the Rahder machine have nearly the same capacity for the production of peat pulp. This gives a result which ultimately yields from 14 to 15 tons of dense turf in air-dried condition for each full working day of twelve hours.

Assuming the peat operated upon to contain 80 per cent. of water, the foregoing quantity will represent 60 tons of raw peat passed through each machine in a full working day of twelve hours—equal to about 200 cubic feet per hour, torn, mixed, and forced out in the condition of pulp.

The machine of the Messrs. Clayton has not yet been tested by working results spread over sufficient periods; and data such as those upon which the foregoing figures are based are therefore wanting. The makers claim, however, that each machine is capable of producing peat pulp which, when air-dried, will give from 15 tons to 20 tons of marketable dense peat for each working day.

When the making of dense turf by mechanism came into notice in Germany, large machines on the pugmill principle were constructed by Schlickeysen, with a view to increased production. They were not, however, found in practice to be as desirable as machines of smaller size, and their manufacture was discontinued. The example of the Schlickeysen machine which has been given represents the principal size now in use. Smaller sizes are also made, which are provided with but a single mouth-piece. The effective treatment of as much raw peat as shall give, on an average, a yield equal to 14 tons or 15 tons of air-dried dense turf for each full working day, seems, in practice, to be the *extreme* useful, economic limit of production at present, by the best examples of mechanism of the pugmill class.

It is submitted that, for general purposes, a rough, effective tearing and mixing of peat in the natural condition, with a moderate pressure to give body to the pulp, are sufficient for the making of good dense turf; and that any elaboration of mechanism, with a view to a more perfect comminution of the peat, is not attended with the benefits which might be expected, or which are sometimes claimed for it.

Some of the German machines, and in general the machines of Messrs. Clayton, are fixtures. The Dutch machine of Rahder differs in this respect. The Dutch peat-mill rests on an iron framework having flanged wheels of the same gauge as those under

the portable engine, which is the motive power, and, as occasion requires, both travel on a pair of rails, laid for temporary use upon sleepers alongside the line of excavation of the peat. In this manner the mechanism follows its work—a consideration of importance where 80 per cent. of the raw material consists of water, which in the case of fixed machinery has to be carried to the place of manufacture.

The Author is of opinion that of existing examples of mechanism of the pugmill class for the production of dense turf, the Dutch machine referred to offers, in design, construction, and arrangement, a useful combination; and that the transportable principle, by which the mechanism shall constantly follow its work, is an essential requisite for economic success where the tract of peat to be worked is extensive.

To the pugmill class belongs also Eichorn's system of Kugeltorf, or "ball turf" manufacture, which has the merit of originality of arrangement for the making and drying of this kind of turf. This system necessitates fixity of location, and the erection of buildings in which height is an essential condition. A rectangular covered building of greater length than width is required for the manufacture. Upon the upper floor of this building, at a height of 30 feet from the level of the ground, the pugmills are arranged in two rows, one row at each side of the building, in the direction of its length. The pugmills are conical, of small internal size, 5 feet high, and at the widest part of the top not more than 20 inches in diameter. In each of these a revolving upright taper screw mixes the peat, and forces the pulp through a round orifice 4 inches in diameter, in front near the bottom of the mill. As the pulp issues it is cut off by a knife, timed in its revolution to the motion of the machine, in pieces 4 inches long. The pieces fall into the narrow ends of conical wooden vessels, each of which revolves upon a horizontal axis immediately below the mills, and by their revolution give a rounded shape to the fragments of peat. These fragments are finally delivered from an opening at the wider end into small wagons, adapted for running upon light rails.

The sides of the building, at the upper working floor, are for the most part open. From each side a wing of timber frame-work extends outwards. The wings are covered by roofs. The floors are of open timber staging, immediately beneath which strong lattice frames of timber, placed in a sloping position at short intervals, reach to within 6 feet or 7 feet of the ground. Upon light rails laid over these frames the wagons run from the mills with the wet peat balls, and are at once emptied into the open spaces

between the lattice frames, where the latter meet the level of the staging, and the peat balls, as they roll down, dispose themselves upon the frames for drying. The inclination of the lattice frames is that which by practice has been found most suitable for this operation. When the turf balls are sufficiently dry, boards near the bottom and at intermediate points, which confine them upon the frames while drying, are withdrawn, and they fall into heaps upon the ground ready for removal and use. As these lattice frames for drying may be each more than 20 feet in length, the necessity of height in the main central building becomes apparent.

In this system the peat is, in the first instance, roughly torn or mixed before being raised by elevators to the upper working floor to supply the small pugmills. In the works at Feilenbach, near Aibling in Bavaria, which were visited by the Author, the screws used in those mills were made almost entirely of wood.

It is evident that the objects of Eichorn consisted more in efforts to solve the difficulties of drying the peat, by a system designed for working during the greater portion of each year, independently of the weather, than in any marked improvements in the macerating or mixing of the peat itself. And it is submitted that where a daily production of peat extending over seven or eight months of the year is to be realised, the task of the engineer largely lies, in connection with effective, and at the same time economical, arrangements for drying.

In contrast with Eichorn's system in this respect, the arrangement introduced by the Messrs. Clayton may be referred to. For each machine, the daily work of which is claimed to be equal to from 15 to 20 tons of dense turf when in air-dried state, nine thousand wooden trays were, in 1873, stated to be needed to keep the work fairly going, one day with another, in addition to the racks and sheds necessary for the reception of these trays. In the former there is the principle of fixed lattice frames, and in the latter that of numerous portable wooden trays for drying.

Next to the pugmill type may be mentioned the class of machines which disintegrate the peat by horizontal rollers, armed with teeth or points, and usually worked at a considerable velocity. In some modern arrangements upon this system the peat torn by the rollers falls into chambers in the lower portion of the machines, and is there still further mixed and forced outwards by spirals or screws. Machines upon this principle are used at extensive peat works in Bohemia. As a matter of preference in the system of working adopted there, the peat pulp thus produced is not separated into pieces as it comes from the machines, but is delivered

into barrows as a general mass of pulp. In this condition it is removed, and formed, by hand and foot labour, into a stratum upon a spreading ground, and is there divided into pieces for drying. The function of these machines consists simply in making the peat into pulp, without any reference whatever to delivering it in a shaped state. At Gratzen, where this method is employed, the machines are all of the transportable class, and constantly follow the excavation of the bog.

Where horizontal toothed rollers are used, the torn peat sometimes falls upon a revolving wooden table, placed immediately beneath the rollers. Upon this table are wooden wheels, free to move on their axes, by which, as the table revolves, the torn peat is subjected to a mixing action. The pulp is then simply removed, and distributed in a stratum on the drying-ground, by an arrangement which parts it into pieces as the distribution proceeds.

With the increased density which turf prepared by any of the foregoing processes possesses over the same description of peat in the state of ordinary cut turf, ranging with *fibrous* peats from 30 to 100 per cent., there is coupled the advantage that peat, when pulped, parts with its water more freely in drying than it does when in the unpulped state. This advantage is increased by the fact that, in all systems that work upon the wet process, the pieces of pulped peat are smaller in cross-section than is usual in ordinary turf. There are, consequently, a greater number of pieces to be handled for a given weight; but this is compensated for by the increased gain in drying.

As far as the subject has now been treated, it may be assumed that the peat is operated upon as it comes from the bog without the addition of water, except in rare cases where, owing to exceptional dryness, water may be required to reduce the pulp to the same consistence with that given by peat containing the average percentage of 80 per cent. of water.

In the French system of Challeton, however, water is copiously added, so as to reduce the peat into a fluid condition. In that state it is pumped up to a staging, where it undergoes filtering for the removal of the grosser portions, and the residuum flows by shoots into shallow settling and drying basins. These are provided in the bottom with arrangements for filterage and drainage; and the peat, when sufficiently firm, is cut into pieces for drying. A fine dense peat is obtained in this manner; but the system is not favourable to large production, and can hardly be held to be an improvement in this respect upon those already mentioned. The large extent of reservoirs necessary for producing even moderate

quantities limits the capability of useful economic production; and unless these reservoirs be protected by roofs from the weather, the period during which they could be advantageously used would be, in these countries, limited to a few months in each year. Assuming these reservoirs to be covered over, with a view to a lengthened period of working during each year, drying sheds would likewise be necessary. This system would therefore require more erections, to enable the working period to be extended over seven or eight months yearly, than any of those already described.

The Dry Process.

This is mainly the German system of Exter, and the only one in which, upon anything like an important scale, density in turf is effected by mechanical force. The peat in this system is, in the first instance, obtained in a fine or powdery state from the surface of the bog. This is effected by a thin horizontal slicing of the surface. The layers or slices break up at once before the action of the surface ploughs which are used for the purpose; and the peat is collected into heaps, and partially dried upon the bog. It is then removed to a capacious shed, covered by a roof, but for the greater part open at the sides, where the drying still further proceeds by ordinary evaporation. As the period, during which the manufacture can be carried on continuously, depends on the quantity of fine peat obtainable in favourable weather, the getting of this material in sufficient quantity forms the special out-door work, upon this system, during the months that admit of its collection and storage in a partially dry condition.

The mechanical arrangement for the manufacture was examined by the Author at works for the making of compressed turf for locomotive use at Kolbermoor, near Rosenheim, in Bavaria, on the line of railway between Munich and Salzburg.

The covered storage sheds, to contain the fine peat in the condition already mentioned, are in immediate connection with the peat factory. According as it is required for use the peat is first subjected to a sifting process for the removal of the coarser portions, and after passing through the sieves it is raised to the upper part of an inclosed chamber in which are wrought-iron drying tables, one over another, heated by the exhaust steam from the engine of the works. Upon each of the drying tables spirals are arranged lengthways, all driven by gearing at the back, which constantly keep the peat powder turned over, and exposed uniformly to the heat as it is moved forward. In its course the peat falls from one table to another, until the openings in the

lower part of the chamber are reached, through which, at a temperature of from 120° to 130° Fahr., and with still a considerable proportion of warm diffused moisture, it falls into the cylinders in which it is compressed. The compression is effected by iron rams or plungers actuated by powerful eccentrics, fixed upon the main shaft of the engine of the factory. The cylinders for compression are fixed horizontally, and are open from end to end; the resistance against which the rams work at each stroke being formed by a portion of the compressed turf previously made which remains in the cylinder. At each stroke the mass of compressed turf is moved forward, and its friction is the measure of resistance necessary for mechanically adding, to the turf already compressed, the portion of fine peat which, at every stroke of the ram, is converted into compressed turf. From the back of these cylinders wooden shoots conduct the compressed turf in continuous lengths to the place for its delivery. It may travel from 15 to 20 feet in this manner, and as it passes beyond the shoots it breaks off, at the overhang, by its own weight, into pieces varying from 9 inches to 12 inches, or thereabouts, in length, which fall ready at once for use.

The advantages of this system may be summed up in the drying of the peat in detail—in the condition most favourable for the purpose in the open air—and in the practicability of carrying on the manufacture nearly all the year round, within doors, if sufficient fine material be obtained and stored during the months in which such work can be done. The drawbacks are, mainly, the outlay necessary for such an erection, the wear and tear of the mechanism, and the high rate of the cost of production. Turf prepared in this manner is more adapted for use in furnaces with strong draught than for domestic purposes.

Cost of Production.

With respect to dense turf made by the wet process, various estimates of cost have of late been put forward. Upon the Continent the investigations directed to the question of cost showed that, in 1872, it varied from 6*s.* to 7*s.* per ton for turf made with mechanism upon the pugmill principle and dried in the open air. In the province of Drenthe, in the Netherlands, dense turf made by the Rahder mill *is sold* at the place of manufacture at slightly under 10*s.* per ton. With a good mechanical arrangement and the present cost of labour in these countries, the total cost of production of dense turf, spread over the result of one full year's expenses, cannot, in the Author's opinion, be safely estimated at

less than from 7*s.* to 8*s.* per ton, in air-dried condition. With the economies, however, which it is not unreasonable to hope for in the progress of an industry so new as that of peat manufacture, the total cost of production may perhaps in time become reduced to 6*s.* 6*d.* or 7*s.* per ton, but not to less. Estimates based upon any lower rates, are, in the Author's opinion, not reliable. In 1872, the cost of compressed turf, made by the system of Exter at the works which have been referred to, was about 12*s.* per ton.

Heating Power.

When it is remembered that the word peat, as regards quality, partakes of the same want of precision as the word coal, when used generally, it becomes difficult to arrive at satisfactory results as to its heating power. In variety of composition peat bogs not only differ between themselves, but the quality of each separate deposit is in itself variable from top to bottom, according to the ages of the successive strata of vegetable matter of which it is composed. Results based on experiments, or upon trials on limited scales, have therefore only partial values. In Southern Germany, however, the use of ordinary cut turf, of dense turf, and of compressed turf, has long become established as fuel for locomotive purposes, and the results there, as compared with coal, may be referred to; premising, in the first instance that, *ton for ton*, all three kinds of turf, other things except density being the same in all, rate alike in their evaporative power, the density or compression being simply the concentration of the original quantity of fuel into a smaller space.

When compared, weight for weight, with coal from the Ruhr (Westphalia), the heating power of German turf for locomotive work upon Bavarian lines of railway stands at little over one-half, or as 2,560 to 5,000. Compared with coal from Bohemia, the heating power of turf is somewhat higher, or as 3,100 to 5,000; and when contrasted with coal from Zwickau, and from Miesbach, it is found to be as the figures 3,230 and 3,945 respectively, to 5,000. Assuming the above varieties of coal to represent both good and inferior qualities for locomotive use, it appears that, weight for weight, the heating power of turf is 60 per cent., or three-fifths that of coal, upon the basis of an average struck upon the four varieties of German coal which have been referred to.

The Author has confined his attention to well-established examples of peat machinery, which were professionally examined by him in the latter part of the year 1872, and his principal aim in this Paper has been to present the distinctive features, and the special points of difference to be found in each.

Although not belonging directly to peat mechanism, the Author may perhaps be allowed to make a few concluding remarks upon some points of the subject. Foremost amongst them he would place the fact, not always fully apprehended, that for purposes of ordinary fuel the advantages of densifying peat are only such as result from the concentration of a given amount of heat in a smaller space than it originally occupied. Upon the practical worth of that concentration the value of manufactured peat as fuel mainly depends. In vicinities of peat bogs, where ordinary peat has been long used, it is not likely that much change will be made in its mode of preparation for local purposes; but the conditions are modified whenever markets at a distance may be profitably open for peat fuel, if its transport can be economically effected. In such case reduction in bulk becomes a consideration of importance.

But besides its use as ordinary fuel, a special value attaches to peat when made into firm charcoal; and to procure charcoal in compact condition from peat, its treatment in the first instance by one system or another of the wet process is essential. In few respects are differences more marked in peat than in the characters of the charcoals obtained from peat in the ordinary condition, and from the same peat when made dense; and the Author thinks that in Great Britain it will be for the preparation of peat for charcoal in the firm state, that mechanical systems working upon the wet principle will in the end find their most advantageous applications.

In other countries the mechanical treatment of peat is in most cases *a necessity*, arising either from inferior condition or from special circumstances connected with the raw peat itself, which necessity does not exist to anything even distantly approaching the same extent in the vast deposits of superior peat found in Great Britain and Ireland. Coupling that comprehensive fact, as indisputable as it is comprehensive, with the stores of coal which exist in Great Britain, the probabilities of commercial success for mechanical peat systems may be sought for rather in the production of a high-class special fuel for particular industries than in the making of dense peat upon a large scale for ordinary fuel. The field for such a charcoal cannot but be a wide one, if it can be produced at a price that will admit of its extended use; and possibly in its manufacture some of the by-products given off in the charring, in the conditions of inflammable gas, tar, and ammoniacal liquor, may be to some small extent profitably utilised. But any efforts in this direction should be approached with well-considered prudence.

The reference now made is suggestive of what was done in Ireland within the last twenty years to obtain paraffin products from peat. In the works established for the purpose only ordinary peat was employed, but as the combustion was assisted by an air blast, no charcoal residue was obtained, and only the ashes of the peat were left behind after its destructive distillation.

In addition to the general results of the heating power of peat already given, the following are particulars of laboratory tests to ascertain *absolute* heating power of three samples of dense peat made from the upper, middle, and lower portions of an Irish red bog. These samples of dense peat were obtained in fully air-dried condition, more than a year and a half ago, and were from that time until the making of the tests, in an open press in a room. They may therefore be considered as having been in the best possible air-dried state. The tests for absolute heating power were made with Thompson's instrument, and were carefully conducted by Professor Galloway, of the Royal College of Science for Ireland. Wigan Cannel coal of a specific gravity of 1·288 was used, which gave an absolute heating power, by that instrument, of 14·30 lbs. of water at 212° Fahr., converted into steam by 1 lb.

The dense peat, No. 1, was made from the light upper fibrous portion of the bog, in colour light brown. No. 2 was from the middle portion, and in colour dark brown; and No. 3 was from the lower part of the same bog, and in colour almost black. The specimens were not selected for trial purposes, but were taken from a general quantity, heretofore made in regular course of work at a small peat works, which had been erected for making dense turf for sale near Mountrath, in the Queen's County.

Samples of Dense Peat tested for absolute heating power.	Specific gravity.	Weight of one solid cubic foot in lbs.	Absolute Heating Power by Thompson's Instrument.	
			lbs. of water at 212° F. converted into steam by 1 lb. of dense peat.	lbs. of water at 212° F. converted into steam by one cubic foot of dense peat.
Dense Peat, No. 1	0·637	39·81	6·05	240·87
„ 2	1·000	62·50	5·50	343·75
„ 3	1·173	73·31	6·33	464·07

In closing this Paper the Author may mention that the most generally useful work in the English language upon the peat subject is that by Professor Johnson, of Yale College, published in 1866 by O. Judd and Company, New York; and for much valuable information from year to year, dealing with the progress of peat industry, reference is made to the principal serial technical publications in Germany, dating from the year 1860.

[Mr. E. A. Cowper

Mr. E. A. Cowper was glad that this subject now appeared to receive more attention than in past years, as so many schemes had been tried, resulting in so many failures, that there was a chance of the whole question being put on one side. In certain cases peat answered very well. Cottagers in the neighbourhood of a peat bog obtained enough to answer their purpose; but they did not create a large manufacturing business. In South Holland, and in some parts of Germany, the peat was mashed up in troughs, and then spread out upon the ground in a layer about 3 inches thick. It was next trodden down by men, with boards attached to their feet, into layers perhaps 20 feet wide and 100 feet long; then cut in lines crossing each other by sharp rakes, turned up, and made into bricks, which were dried in the open air. The plan of digging the turf, turning it over, and drying it on the bog, was a simple and economical mode of proceeding, and thousands of tons were so prepared. He had several samples which had been dried naturally. One piece, from Ely, weighed 5 lbs. 9½ oz. when cut, and less than 1 lb. when dried. Another piece, from Inverness, was in a mashed state, and the finger could be easily thrust into it. Other pieces were reduced to about one-sixth of their original bulk and weight in drying. An enormous mass of material had to be dealt with to produce a very small result: hence the labour employed should be reduced to the lowest possible amount. He greatly preferred drying the peat in the open air to drying it in sheds, where the proximity of the pieces to each other prevented a free circulation of the air. The rain was not a matter of importance, because after the peat had been exposed about twenty-four hours it resisted the rain admirably, and would dry, after being wetted, like a piece of wood. Of course it would not do so in the open air in the rain; nor yet in a shed, because the air would be saturated with moisture. When many pieces were put one above the other and close together in a shed, it was only the outside pieces that caught the wind and the sun, and dried quickly. The next point was, how best to save the cost of carriage. He thought the plan adopted in Holland, of making the machine follow the excavation, the peat being mashed and dried in the open air, was the right one. It had never, however, been tried in England, Scotland, or Ireland, though many machines had been used to compress peat artificially. It was impossible to squeeze the water entirely out of good mashed peat; it must be done by air. He had a plan, by which, at an expense of about £1,800, 20 tons of peat per day might be produced. The bog was supposed to be divided into patches or compartments 240 feet in

diameter. The machine was placed on a truck running on a railway, and as the peat was mashed it was delivered by boys on to the block indicated. Then the machine was moved forward to other patches successively, until a considerable breadth on each side was covered throughout the length of the railway. After travelling in that way for about twenty days, the first patch would be quite dry; it was then cleared off, and the engine set to work again. It might be asked why it was proposed to work in a long line, instead of adopting a stationary engine, and having the work more compact? The extent of the surface of the ground was so great, that unless the engine was moved along on the railway, covering each patch of ground with peat, the workmen would have to walk a considerable distance to deliver the peat. In order to dry the peat mashed by a machine that would make, say 20 tons of dry peat per day, a patch of ground would be required 1,600 feet in diameter; and, owing to the distance the boys would have to walk, and the number of tramways that would be required, the cost would be about £6,000, instead of £1,800. On a smaller scale, with a machine capable of being turned by a pony or two men, a gang of two boys and two or three men, working a patch 70 feet square each day, would deliver from 5 tons to 6 tons of peat, to produce 1 ton of dry peat.

Mr. H. Clayton observed that a pugmill had been used for working peat at Garnkirk Moss as far back as 1837. Mr. Slight, curator of models and machines in the museum of the Highland and Agricultural Society of Scotland, had treated of this mill and the process of manufacture there pursued, in a letter published in the "Quarterly Journal of Agriculture and Transactions of the Highland and Agricultural Society of Scotland."[1] The Author had failed to draw the distinction between the action of the ordinary pugmill knives upon peat, and the action of the arrangement of the fixed and movable cutters in the machines manufactured by his firm. The first merely tore asunder the entangled fibres of peat; while the knives of the latter comminuted all the fibrous matter, and produced an admixture of the whole body of peat. The comminuting action was indispensable for producing dense peat from fibrous turf by the wet process. If the fibre were not completely cut up into small pieces, the drying occupied a long time, and the quality of the fuel was inferior. With respect to the assertion that the Clayton machine was a fixture, this was not indispensable; the transportable system might be applied equally

[1] *Vide* No. xli., p. 331, *et seq.*

to this as to any of the existing processes where the ordinary wet system of manufacture was pursued; but he was of opinion that the machinery should only be moved every two or three years, as the surrounding peat was cleared away. In Germany many manufacturers had for years past received the peat blocks on boards or trays as they were delivered from the pugmill. Many thousands of trays were thus used and might be seen, even near Berlin. The actual cost of production was under 4*s.* 6*d.* per ton by his firm's process in England. In Germany 3*s.* 6*d.* per ton covered all expenses; indeed the entire apparatus was kept going, from beginning to end, by ten men and ten boys, the production of fuel being from 20 to 25 tons per day by one machine, peat being used for working the engine. Wages at 3*s.* 6*d.* per day for men, and at 1*s.* 6*d.* per day for boys, would leave a margin of 100 per cent. in England for trade charges, rent, &c.; in Germany, wages for men at 1 thaler, and for boys at 10 silver groschen per day, would allow 75 per cent. for similar charges. In County Donegal, the cost per ton was 2*s.* 2*d.* of the dry fuel, treated by the Clayton machine.

Peat fuel, of an inferior quality, when treated by the Clayton system, would evaporate from 5 to 5¼ lbs. of water per lb. of peat; but when the peat was naturally decomposed, as much as 6 lbs. had been evaporated. Fibrous peat, if not effectually condensed, could not be used with economy where strong draughts were required, as in portable or locomotive engine work, since, owing to the friable nature of the non-condensed peat, a large portion was carried away by the draught unconsumed.

Colonel A. R. Wragge said that natural drying processes having failed, it was desirable to adopt a system of artificial drying which would be quite independent of atmospheric conditions. This might be accomplished by bringing peat upon wagons into a drying chamber of sufficient dimensions to contain a large quantity, and by exposing the peat to a gradually increasing temperature. The result would be that the evaporation would increase somewhat in geometrical progression, while the temperature would increase merely in arithmetical progression. Beginning at 10° C., 3·7 grains of moisture would be evaporated; but at 100° C., 245 grains would be evaporated: by thus increasing the temperature tenfold, the evaporating powers were increased sixty-fourfold. By this means of artificial drying, which could be carried on throughout the year, large quantities of peat might be produced to supplement the supply of coal.

Mr. A. McDonnell observed that he did not think such a machine as the Messrs. Clayton's was desirable. Cutting peat was often a

matter of extreme difficulty, and the machine was frequently choked in the attempt. In ordinary bog there was a large quantity of what was called horseflesh, the cutting of which, from its tenacious and slippery character, was an impossibility. From experiments he had tried, he thought the first cost of making peat would amount at least to 5*s.* 6*d.* a ton. He had employed peat in a stationary engine, a locomotive, and also in Siemens' gas furnace. He ran a light goods train 347 miles with ordinary cut turf, and the consumption was 73·9 lbs. per mile. The same engine ran the same distance a short time before with a somewhat heavier load, and the consumption was 36 lbs. of coal per mile—the amount being large, owing to the many delays on the journey. The average consumption of such a train would be about 32 lbs. of coal per mile. This trial would give 100 parts of peat, equivalent to from 41 to 43 parts of coal. He also ran a passenger train 520 miles, the average load being 7·6 carriages (the six-wheel heavy carriages used in Ireland), the maximum load being 14 carriages; the speed was 29 miles an hour, and the consumption of peat 51·6 lbs. per mile. The same engine ran 663 miles, with an average load of 6·4 carriages, at an average speed of 30 miles an hour, and the consumption was only 20·3 lbs. of coal per mile, but in the previous four weeks, it was about 21·6 lbs. per mile. That experiment would give nearly the same proportion of peat to coal, namely, 100 parts to about 41. With a stationary engine, he found that 36½ cwt. of peat was equivalent to 17½ cwt. of coal, working for one day, which was rather a better result, showing a proportion of 100 parts of peat to 48 of coal. Another experiment with a stationary engine showed that 65 cwt. of peat was equivalent to 27 cwt. of coal, giving a proportion of 100 parts of peat to 43 or 44 parts of coal. He thought the best method by which peat could be used with advantage was in a Siemens' gas furnace. In trials last year, in forging iron, he found that 1 ton of finished forgings required 4·96 tons of coal in an ordinary air furnace; while the same quantity of iron was forged with 5·09 tons of peat in a Siemens' gas furnace. In the case of the gas furnace the loss in the iron was from 5 to 6 per cent. less than when the iron was heated in an air furnace. The result was that the finished forgings in one case cost £22 14*s.*, and in the other £18 6*s.* This referred to the cost of making the peat. The price of coal was 28*s.* a ton, and the peat was taken at what he considered the extravagant price of 14*s.* a ton. To ascertain how quickly the peat might be used after being cut from the bog, on the 1st of April, 1874, he cut some peat, mixed it up in a machine, and dried

it in the air; on the 29th of April it was used for forging coupling rods, when it contained probably not much less than 40 per cent. of moisture. The amount of heat from fuel of that kind, in a gas furnace, did not appear to be limited in any way; and it would be as easy to make steel as to forge iron.

Mr. Bramwell thought Mr. McDonnell was about to compare the cost of making a hundredweight of forgings in an ordinary furnace with coals, in Siemens' furnace with coals, and in Siemens' furnace with peat.

Mr. McDonnell said he had only tried coal in Siemens' furnace for a week, which was too short a time for an average to be taken. As far as he had gone, it required 3·3 tons of coal in Siemens' furnace to forge a ton of iron, whereas it took 5 tons of peat to forge the same quantity.

Mr. Siemens said, in the course of the discussion, the use to which the peat was to be applied appeared to have been left out of sight. If it was to be worked into peat charcoal, it was of course necessary that it should be thoroughly masticated and compressed, in order to make it of great density. Such peat charcoal was of considerable value, and in blast furnaces he thought it would be better than the best coke that could be obtained, because it was generally free from sulphur. This, however, was not always the case, for at Swansea he had analysed peat, and had found it to contain fully $\frac{1}{2}$ per cent. of sulphur, owing, no doubt, to the presence of the Copper Smelting Works. Again, if peat was required for locomotive work it must be rendered dense, or it would fly out in large quantities from the chimney; in which case a machine like the Messrs. Clayton's might be extremely useful. If, however, peat was only to be used for the production of heat, in stationary steam boilers or in furnaces, it would be entirely useless to subject it to manufacturing operations such as had been described. He agreed with Mr. Cowper in thinking that it was desirable to separate each piece as much as possible from its neighbour, so as to let the wind act upon it, rather than to dry it in sheds by artificial heat, because in the latter case a large proportion of it had to be burnt to produce the heat, and the operation was actually retarded because only a limited quantity of air could be brought in contact with each piece. Air-dried peat, containing 40 or 50 per cent. of water, was capable of producing any degree of heat if properly burnt; and he considered the proper way of burning such fuel was to convert it into a gaseous fuel. The gas was as rich if the peat contained 50 per cent. of moisture as if it contained none; but care should be taken to condense the water

out of it before the gaseous fuel was used. He had employed peat so treated for forging furnaces and steel melting furnaces, and found it the best fuel that could be used. He should prefer it even to the best coal for heating purposes, and he believed the time would come when the stores of peat in Ireland, in Scotland, and in the north of England would form a valuable addition to the stock of fuel for all operations for which coal was at present used. Such employment would tend more than anything else to the development of iron industry in Ireland.

Mr. Cowper said the hard fuel could be carried without injury, whereas the lighter descriptions when conveyed in a truck would fall to pieces, and were too light to make a good truck load.

Mr. F. H. Danchell remarked that there was no difficulty in macerating and drying peat on a small scale; the difficulty was to make it on a large scale. In France and Germany excellent peat was produced for 4*s.* or 5*s.* per ton; and he had himself contracted in France, where wages were as high as in England, to deliver it at 5*s.* In such cases small quantities only were made, say 4 or 5 tons a day, by three or four men, but all attempts had failed to produce peat at that price in large quantities. He thought that peat should not be macerated too much, as it was then liable to split into fragments. The density of the charcoal depended greatly upon the mode of charring. The slower the charring process the more dense the charcoal. He had in that way made the densest charcoal from comparatively loose peat. Seeing the rate at which peat could be produced elsewhere, he did not understand why the Author should adopt a minimum cost of 6*s.* 6*d.* or 7*s.* That was of course only an opinion; but in such matters opinions did not go for much unless they were based upon actual data.

Mr. Meadows, in reply, said his calculation of the cost was founded in the first place upon the present cost of ordinary peat obtained in the simplest way. It was cut by the spade, removed to the bank, taken on barrows to the drying ground, turned and spread by women and boys, and ultimately heaped together; and at the present price of labour in Ireland the total cost, including all charges, was not less than 4*s.* 6*d.* a ton. It was necessary now to provide for payment of able labour for cutting peat in quantity in Ireland at the rate of 3*s.* 6*d.* a day, and proportionate advances had taken place in the wages of women and children. Ordinary peat, which in the centre of Ireland might formerly be made for 2*s.* 6*d.* a ton, could not now be produced in bulk for less than 4*s.* 6*d.* Besides the charges for the extraction and preparation of the peat, there were the expenses of removal and treatment in the

machines, with other attendant expenses, which could not amount to much less than 2*s.* or 2*s.* 6*d.* additional per ton. With regard to the system of sheds, it should be remembered that the period for working without them was limited, and that without the use of sheds a large quantity of peat could not be conveniently produced. He thought a removable shed arrangement would not be found impracticable. With regard to the pugmill, possibly it had been used for peat before the time of Weber, but he believed its introduction as a recognised mode of treating peat did date from the time he had stated. As to the *spécialité* of the Clayton machine he would simply state that samples of peat made by the different processes could be easily obtained, by which any one could judge how far the mechanical refinements claimed for that machine were valuable or otherwise. He thought the inherent difficulties surrounding the production of peat were almost less obstructive to the progress of the manufacture than were the statements sometimes made as to the extreme cheapness of its production. The statement that dense peat could be produced during a considerable period of the year for 2*s.* 2*d.* a ton, presented, in his opinion, one of the greatest difficulties in connection with the progress of the subject.

Mr. R. Mallet observed, through the Secretary, that, in his opinion, the Author had over-estimated the financial saving to be effected by the employment of peat fuel. He held the same views on the subject as in former years.[1] The hot summer sun, in the dry climate of Bavaria and Bohemia, would be far more effective in drying peat than the damp atmosphere of Great Britain.

Mr. A. McDonnell, in a subsequent communication to the Secretary, gave the results of the trials of coal and peat in Siemens' regenerative gas furnace, for three weeks, as follows:—

One ton of iron, forged from scraps into finished locomotive forgings, required 2·86 tons of rather small Welsh steam coal, in Siemens' regenerative furnace; it required 4·96 tons of Ruabon coal in the ordinary air furnace; and 5·09 tons of air-dried peat in Siemens' regenerative furnace.

When manufactured by machinery, the peat, reduced to pulp by the machine, was received on small trays made of laths, which were placed on small wagons, with spaces between to allow the air to circulate. A tray held $\frac{1}{3}$ cubic foot of pulped peat. A wagon held 240 trays, or about 80 cubic feet of peat. A cubic

[1] *Vide* Transactions of the Institution of Civil Engineers of Ireland, vol. i., p. 1.

foot of pulped peat weighed 63 lbs., which was 10 or 12 lbs. more than a cubic foot of the wet bog. The wagon held rather more than 2 tons of wet pulped peat. The quantity of air-dried peat which this produced varied with the quality of the bog. A wagon load made from peat taken from 6 feet below the surface of the bog gave 8 cwt. of dry peat. If made from a bog of good quality, the wagon load would produce from 9 to 10 cwt. of dry peat. If made from mountain bog, it would probably produce 12 cwt. or more. Two cubic feet of peat passed through the machine in a minute, or about 120 cubic feet in an hour. The cost of making a wagon load was 3*s.* 2*d.*, including drying the peat and loading it into railway wagons. This could probably be reduced if the peat had not to be raised from so low a part of the bog, and if there was greater space for drying. If the bog produced 8 cwt. a wagon load, the cost of making a ton would be 7*s.* 11*d.*; and if the bog produced 10 cwt. a wagon load, the cost would be 6*s.* 4*d.* a ton. He thought the cost of making a wagon load might be reduced to 2*s.* 10*d.*, and with very good arrangements to even less. In this case a ton of peat from the bog, producing 8 cwt. a wagon load, would cost 7*s.* 1*d.*, and from that producing 10 cwt. a wagon load, 5*s.* 8*d.* The cost of making peat from very good mountain bog would of course be less. Thus the cost of making a certain cubic quantity of wet peat was nearly the same for all qualities of peat; but the cost of the dry manufactured peat depended on the quantity of dry peat produced from a certain cubic quantity of wet peat. It might, therefore, pay commercially to make peat from a good bog, when it would not from an inferior one.

He had tried peat against coal in a stationary engine worked very carefully. The result was that 59½ cwt. of coal kept up steam for two days, and 120¾ cwt. of air-dried peat kept up steam for a similar time. The quantity of water fed into the boiler was nearly the same in each case. This would give 100 tons of peat as equivalent to 49·3 tons of coal. He also tried extremely inferior moss turf for two days, in the same boiler, and the consumption was 176 cwt.; this gave 100 tons of such peat equivalent to 34 tons of coal.

In another trial of peat in a locomotive with a passenger train, the number of miles run was 694; average load, 7·1 six-wheeled carriages; speed, 29 miles an hour; peat burnt, 15 tons 3 cwt.; consumption per train mile, 48·9 lbs. The average consumption of coal with the same train had been from 22 to 23 lbs. a mile. This would give 100 tons of peat as equivalent to from 45 to 47 tons of Welsh coal.

Mr. F. H. Trevithick observed, through the Secretary, that in the year 1868 he rode on a goods engine on the Grand Trunk railway of Canada several consecutive journeys, over a total distance of 683 miles. The weight of the train, exclusive of engine and tender, was 428 tons, and the maximum gradient of the railway 1 in 100. The fuel used was dense peat. There was no difficulty in keeping up steam, and it was not necessary at any time to have the fire-box more than half full of peat.

The consumption of peat per mile of train run, including the fuel used in getting up steam, was . . .	lbs.	70·1
Number of miles run by train per ton of peat consumed	„	31·6
Price of peat per ton	dols.[1]	3·90
Cost of peat consumed per train mile run . . .	cents.	12·43
The average running speed per hour was . . .	miles.	15·8

At Fond-du-Lac, in the United States, in 1869, the following work was performed by one of Hodges' 18 HP. peat machines :—

A canal was cut in a peat bog in thirty-seven working days of ten hours each	7,699 feet long.
Width of canal	19 „ 6 in.
Depth of canal	5 „ 6 „
Greatest length of canal cut per day	314 feet.
Greatest amount of peat excavated per day . .	1,020 cubic yards.
Average length of canal cut per day	208 feet.
Average quantity of peat excavated per day . .	676 cubic yards.
Greatest quantity of dense peat fuel made per day	114 tons.
Average quantity of dense peat fuel made per day	76 „

In estimating the quantities of dense peat made per day, 15 tons had been taken as the produce of 100 tons of raw peat.

In 1870, the cost of making dense peat in Canada by Hodges' machines was $2·37 per ton, including repairs of machinery, superintendence, office charges, and loading the peat in trucks at the bog, and subsequently unloading and putting it into sheds in the yards of the purchasers. The quantity produced at the above rate was 13,000 tons. In the half year ending December 1873, 10,551 tons of dense peat manufactured by the above machines were consumed on the Grand Trunk railway of Canada. The cost of this fuel per train mile run, compared with other fuels, was as follows :—

Firewood	cents.	10·97
Peat	„	12·83
Coals	„	16·30

[1] One dollar = 4*s*. 2½*d*. ; one cent = one halfpenny.

The price of the respective fuels was —

Firewood, per cord	dols.	4·75
Peat, per ton	„	4·00
Coal, per ton	„	6·40

It would be observed that a large difference was shown between the rates of working with wood, peat, and coals. The coal was used on sections of the road where wood was dearest, and the loads hauled by the coal-burning engines were much heavier than those hauled by engines burning peat or wood.

He erected, last year, a peat machine at Campe, in Oldenburg, Germany, similar to those used in America and Canada on Mr. Hodges' plan. It was, he believed, the only one of the kind on this side the Atlantic. It was constructed to cut about 8 feet deep by 20 feet wide. If it were desired to cut deeper, it would be necessary to take a second cut after the whole surface of the bog was removed for a depth of 8 feet, and for this purpose the surface-water must be allowed to run off.

Mr. David Stevenson remarked, through the Secretary, that the subject was interesting as connected with manufactures, and especially in the present state of the coal trade. He thought the general conclusions of the Author were perfectly sound; and he was led to this opinion from inquiries he had made on the subject in connection with the Highland and Agricultural Society of Scotland, for which he acted as consulting engineer. The employment of peat fuel by the inhabitants of some large districts in Ireland, the northern counties of Scotland, and elsewhere, naturally suggested a more general use of that fuel for household and manufacturing purposes. In the Highlands of Scotland the cutting or 'casting' of peats was commenced early in the season. After being cut they were left to be dried by the sun—a process which was fast or tedious according to the state of the weather. After being thoroughly dried, the peat was collected and stacked for winter use.

In order to make peat suitable for exportation, and generally useful as a fuel, it was necessary, first, to compress its bulk, and, secondly, to remove the water, amounting to about 80 per cent. An attempt to accomplish this twofold object by simple compression, by machinery, was made on a large scale at Colzium Moss, near Edinburgh, so long ago as 1830; but after considerable outlay in erecting an engine-house and machinery it proved unsuccessful. Several ingenious contrivances had since then been made. No doubt the thorough maceration of the peat facilitated the

expulsion of water; but it was undeniable that the fibrous texture of the peat enabled it to retain much moisture, notwithstanding any amount of maceration and compression hitherto applied to it in the ingenious machines employed; and he knew from personal inquiry that this had proved a great difficulty in the employment of peat-compressing machines. It was not easy to see how this moisture could be removed otherwise than by the old process of drying in the open air, which required a large space, and was wholly dependent on the weather. This, then, was the practical difficulty which had hitherto attended the manufacture of peat fuel, and unless it could be overcome the profitable manufacture of peat fuel in this country could not be regularly and continuously carried out on a large scale. The improvers of peat-making apparatus should therefore, he thought, apply themselves to the best means of effecting its speedy desiccation.

Mr. H. P. Fenton, Her Majesty's Consul at Munich, in a report dated March 1867, "on the use of Turf as Fuel for Railway Engines, and on the mode of preparing the Pressed Turf used for that purpose in Bavaria," stated that—

"The first experiments with turf as fuel for railway engines were made on the Government railways of Bavaria towards the close of the year 1845, about five years after the opening of the first Bavarian railway; and these succeeded so well, that it was soon afterwards decided to despatch one of the regular trains—that running between Oberhausen and Nordheim (in the neighbourhood of Augsburg)—with an engine burning turf only. The journey was performed successfully, the turf (which was used in the rough or unprepared state, as cut from the moor) having been found equal to the production of the steam power required for propelling the engine at the usual rate of speed attained when fire-wood was employed. The only alteration which it was found necessary to make in the heating apparatus of the engine, in order to adapt it to turf fuel, was the raising, to some extent, the fire-bars in consequence of the flame from the turf not rising so high as that from wood, and therefore not producing the proper effect on the boiler when the fire was placed as low as had been customary. The distance performed by the train on this occasion was 15 German miles ($4\frac{61}{100}$ English miles each), and the quantity of turf consumed was 3,527 Bavarian pounds (about $26\frac{1}{2}$ cwt. English). As compared with the average consumption of wood—which at that period was the fuel chiefly used on the Bavarian railways—this result was very satisfactory, the difference in the cost of the fuel having been as five to six in favour of the turf.

"Experiments on a larger scale were subsequently made for two or three weeks consecutively with two engines, the one heated with turf, and the other with wood, for the purpose of testing more accurately the relative cost of the two descriptions of fuel. Although the difference was not found, in the long run, to be so great as on the occasion of the first trial, the advantage remained decidedly on the side of the turf. At the same time the practicability of producing, by means of turf fuel, the requisite steam power for engines, even when drawing heavy trains, was placed beyond all doubt.

"It was in consequence determined, with a view of introducing the system of turf-firing on the State (or Government) railways, to turn to account a large tract of turf land lying between Munich and Augsburg—known as Haspelmoor — and belonging to the State. In the course of the summer of 1846 above 700,000 cubic feet of turf were cut from it for the use of the railways. At first some difficulty was experienced in drying the turf sufficiently to make it really serviceable, as its efficiency as fuel for engines was found to depend, to a great extent, on its being thoroughly dry. But this difficulty was, in a great measure, overcome; and by the month of May 1847, it was found practicable to dispense with wood-firing on the southern section of the State railways, and to establish the system of turf fuel in its stead.

"But the great bulk of the turf, in its rough state, proved a source of considerable inconvenience and expense, as it rendered necessary the erection of vast magazines for storing the turf under cover, and also made it indispensable to employ two tenders instead of one with every engine.

"With the object of remedying these evils, by reducing the original bulk of the turf, a system of manipulation was introduced, towards the beginning of the year 1849, by which the turf, before being employed as fuel, was reduced to a comparatively compact substance; and an establishment for preparing turf according to this system was put on foot at Haspelmoor. The process was similar to that of the first stage of brick-making, that was to say, the turf was broken up, mixed with water, and well kneaded to the consistency of clay; and was then formed into squares or bricks, which were placed under sheds to dry.

"Turf treated in this manner, and known as prepared or moulded turf, was found, notwithstanding the water used in the process, to dry more rapidly, and, when once dry, to be less liable to imbibe damp, than turf cut from the moor in the ordinary manner, and left to dry in its original state.

"It formed a tolerably compact mass, less bulky by one-third to a half, in proportion to its weight, than common unprepared turf, and was found to answer very well as fuel for engines, whether employed in drawing passenger trains or heavy goods trains. But it was found impossible to prepare a sufficient quantity of turf of this description to supply the increasing requirements of the railways as fresh lines were constructed; and the bulk of the turf, even in this form, still caused inconvenience. Trials were consequently made, with the object of producing, in larger quantities, a more completely condensed description of turf with a system of pressing by steam. After several experiments, the administration of the State railways established, in the year 1858, a factory at Haspelmoor, for the purpose of carrying into effect a system of this kind.

"The process adopted, and which was still pursued at the present time, consisted in reducing the turf to powder, or nearly so, by means of breaking up and sifting, drying the powdered turf in an oven, and then pressing it while in a dry state by means of a steam press, which transformed it into hard, solid cakes.

"He had obtained, from a gentleman connected with the Engineering Department of the Bavarian State railways, a memorandum containing a detailed description of the whole process of preparing and pressing turf according to this system, as well as of the apparatus made use of. A translation of that memorandum was annexed as a separate document.

"Turf pressed according to this system was reduced to about one-third of its original bulk; but it would appear that this reduction in the volume, and the absence of moisture, alone constituted the advantages of the process, as it seemed to have been ascertained beyond doubt that the pressed turf did not, in proportion to its weight, produce a more intense degree of heat than ordinary unprepared turf, when properly dried. On the contrary, the intrinsic quality of the turf was supposed rather to suffer than to gain by the process of sifting and pressing. But by the great reduction in the bulk, no doubt the chief practical objection to the use of turf as fuel for railway engines, namely, the space it occupied, was, in a great measure, removed.

"It would not appear, however, that up to the present time pressed turf had been brought exclusively into use on the Bavarian railways, the quantity consumed on the State lines—on which alone turf fuel in any shape was employed—constituting, according to the latest returns, only about 8 or 10 per cent. of the total consumption of turf on those lines. This was, perhaps, to be

accounted for by the fact that hitherto the employment of pressed turf had been considered rather in the light of an experiment than as an established system; and that, therefore, its manufacture was as yet limited to what the one establishment at Haspelmoor was able to produce.

"It had already been stated that in the year 1847 the system of turf fuel was universally adopted on the southern section of the Bavarian State railways. Since that period considerable additions have been made to the southern network; and on all the lines composing it, turf, either in the rough state or pressed, had been constantly, and still was, employed as firing for engines, almost to the exclusion of all other fuel. The southern network consisted of the line between Munich and Ulm (on the frontier of Wurtemburg), and of all those lying to the south of that line and to the south of Munich, and constituted about half of the entire network of railways belonging to the State.

"But turf fuel had scarcely been adopted on any portion of the northern section of the State railways, except on part of the line between Augsburg and Gunzenhausen, coals or coke being made use of almost exclusively on all the lines which lay north of the latter place. This was easily accounted for by the fact that the coal used as fuel for railway engines in Western and North-Western Bavaria was imported chiefly, if not entirely, from Saxony and Rhenish Prussia (scarcely any of the coal found in Bavaria itself being adapted for that purpose), and found its way into Bavaria through the stations (belonging to the State lines) of Hof and Aschaffenburg, situated, respectively, on the extreme north-east and north-west frontiers of the kingdom. Consequently, all the Saxon or Rhenish-Prussian coal required for use in Southern Bavaria had to be conveyed from one end of the State to the other, at an expense for carriage nearly equal to its cost at either of the above-mentioned frontier stations. The natural consequence was, that the price of coal was nearly twice as high in the southern as in the northern districts of the State. Turf, on the other hand, was found in abundance in several localities in the south; and, in comparison with coal or wood, was extremely cheap. Hence the use of coal on the northern, and turf on the southern divisions of the Bavarian State railways. As regarded the advantages, in an economical point of view, of the use of turf as fuel for railway engines in Bavaria, the following details, procured from an official source, showed the results obtained on the State railways. These were, as it had already been stated, the only railways in the Bavarian dominions on which turf fuel, of any kind, was used,

coals or coke being alone employed on all other Bavarian lines, namely, those of the Eastern Company, and those of the Trans-Rhenane Province of the Palatinate. The former (which intersected the whole of the eastern and north-eastern portions of the kingdom) were in direct communication with Bohemia, where coal was extremely cheap, and used exclusively coal from that country. The latter derived their supplies from the rich coal district through which those railways passed, and from the adjoining coal districts of Rhenish Prussia.

"The administration of the Bavarian Government railways stated the average cost of the different descriptions of fuel employed by them to be as follows :—

Ordinary turf (at the place where it was produced), fl. 3 30 ks. = 5*s.* 10*d.* per 100 cubic feet.[1]

Pressed turf (at the place of manufacture), 22 kr. per 100 zoll pounds[2] = 12*s.* 5*d.*, per ton English weight.

Saxon coal (at the station of Hof), 24 krs. per 100 zoll pounds = 13*s.* 6*d.* per ton English weight.

Ruhr (Rhenish Prussia) coal (at the station of Aschaffenburg), 28 krs. per 100 zoll pounds = 15*s.* 9*d.* per ton.

From experiments made on the State railways, with the object of testing the heating power of each of these different descriptions of fuel, it had been ascertained that, taking an average, they bore the following proportion one to the other :—

100 cubic feet of ordinary (unpressed) turf = 1,200 zoll pounds of pressed turf = 700 zoll pounds of coal (Saxon or Rhenish-Prussian).

"The following would, therefore, be the scale of cost, in proportion to its heating power, of each of the four different kinds of fuel :—

	fl.	ks.		*s.*	*d.*
Ordinary turf (100 cubic feet)	3	30	=	5	10
Pressed turf (1,200 zoll pounds)	4	24	=	7	4
Saxon coal (700 zoll pounds)	2	48	=	4	8
Ruhr coal (700 zoll pounds)	3	16	=	5	5

"This showed a decided advantage in favour of coal; but, as would be observed, the figures represented the cost of the turf in the southern locality, where it was produced; and the cost of the coal delivered at the stations of Hof and Aschaffenburg (previously referred to), on the northern frontiers of Bavaria. If, therefore,

[1] The Bavarian foot is less, by a small fraction, than the English foot, viz., $1\frac{4}{100}$ Bavarian = 1 English foot.

[2] 100 zoll pounds = $110\frac{1}{4}$ lbs. avoirdupois.

the expense of carriage to the south—which could not be calculated at less than from 80 to 90 per cent. on the cost—were added to the prices paid for coal at the northern stations above mentioned, the relative cost of the different kinds of fuel, in proportion to their heating power, would stand about as follows, in the southern districts:—

	fl.	ks.		s.	d.
Ordinary turf (100 cubic feet)	3	30	=	5	10
Pressed turf (1,200 zoll pounds)	4	24	=	7	4
Saxon coal (700 zoll pounds)	5	22	=	8	11
Ruhr coal (700 zoll pounds)	5	50	=	9	8

—the difference being greatly in favour of the two descriptions of turf fuel.

"The result would therefore appear to be, so far as the question of cost price was concerned, that, while coal was the most economical description of fuel in the northern part of Bavaria, turf was decidedly more advantageous in the south; especially as the average price of fl. 3 30 ks. per 100 cubic feet of ordinary turf, as assumed by the railway administration, must be considered an extreme one in Southern Bavaria.

"Independently, too, of the apparent advantage with respect to price, other considerations might be supposed to weigh in Bavaria in favour of the turf fuel for railways belonging to the State, wherever it could be adopted without positive loss. Turf was the produce of the country itself, whilst the coal employed for railway engines was imported from abroad. In the digging and preparing of the vast quantities of turf consumed on the railways of Southern Bavaria (12,511,696 cubic feet of ordinary, and 6,167 tons of pressed turf in the year 1865) employment was provided for many hundred individuals of the native population, and that, too, in districts which (from the usual poverty of the soil where turf existed) the demand for labour was, as a general rule, limited.

"There were also some special advantages as regarded the railway engines themselves, in connection with the employment of turf fuel, on which considerable stress was laid by the administration of the Bavarian State lines. These were—

"1. Turf, being entirely free from sulphur, produced a much less detrimental effect on the heating apparatus and boiler of the engines than coal or coke, so much so, it was stated, that where turf was used those parts of the engines (*cæteris paribus*) would last nearly three times as long as where coal or coke was burnt.

"2. The dust or ash from the turf, being not nearly so hard or gritty as that from coal or coke, caused much less damage to the

engines from friction; they also required less repairing and painting, and were much more easily kept clean.

"3. The turf, when properly dried, and especially the pressed turf, caused but little smoke, and none of the noxious sulphurous vapour produced by coke.

"On the other hand, as already stated, the drawback to the use of turf, in its ordinary or unprepared condition, consisted in its great bulk, which was productive of serious inconvenience, and of expense in a variety of ways. This defect, though considerably diminished, was by no means overcome in the case of the pressed turf; as, even in this condensed form, its bulk, in proportion to its weight and heating power, still remained considerably greater than that of coal. Another, though minor disadvantage attaching to turf fuel, was the great quantity of dust it produced, which found its way from the engine into the passenger carriages in a very unpleasant manner..

"With respect to the mode of using turf fuel on the Bavarian railways, it was said that it was always employed alone, that was to say, not in combination with any other description of firing. The only alteration found to be necessary in the usual apparatus of the engines, in order to adapt them to turf fuel, was that of raising the fire-bars about 8 or 10 inches above the ordinary level, so as to prevent there being too great a space between the surface of the burning turf and the upper part of the furnace.

"It might as well be stated that firewood was no longer made use of on the railways of Bavaria, except for the purpose of lighting the fires of the engines, the cost being considerably greater in the north than that of coal, and in the south than that of turf. In the southern districts the average price of ordinary firewood (fir) might be assumed at fl. 7 30 ks. (12*s.* 6*d.*) per klafter (126 cubic feet). Two-thirds of a klafter of such wood being calculated to produce as much heat as 100 cubic feet of ordinary turf, or 1,200 lbs. of pressed turf, the cost of wood as compared with turf would be as follows :—

	fl.	ks.		*s.*	*d.*
Wood (two-thirds of a klafter)	5	0	=	8	4
Ordinary turf (100 cubic feet)	3	30	=	5	10
Pressed turf (1,200 lbs.)	4	24	=	7	4

"In conclusion, some general observations on the subject of turf fuel, furnished by the gentleman who was at the head of the department of the Bavarian Government under which the administration of the State railways was placed, and who had especially

given his attention to all matters connected with the management and practical working of railways, were as follows:—

"'According to my experience, the great advantage connected with the use of turf as fuel for railway engines consists in its much less injurious effect on the machinery than that produced by coal.

"'But I must also observe that scarcely any article offers such marked variations in respect of quality as turf. When, therefore, the word "turf" is made use of as meaning turf in general, great misunderstandings and miscalculations may be the result.

"'The proportion assumed of

> 1 cubic foot of ordinary (unprepared) turf = 12 zoll pounds weight of pressed turf = 7 zoll pounds weight of turf,

is correct as regards the turf of Southern Bavaria, now made use of on our railways; but it would not apply to turf from moors in other districts; and, in fact, can scarcely be considered as more than an approximative calculation, even with the turf of Southern Bavaria, as it frequently occurs that the quality of turf cut from different parts of the same moor varies considerably.

"'The great bulk of turf, in proportion to its heating power, creates serious difficulties; and the larger the scale upon which the turf is used, the greater do these difficulties become—which is the reverse of the rule generally applicable to matters of this kind.

"'It is with the object of overcoming these difficulties that the various systems of pressing or condensation have been introduced. But there is no doubt that, independently of the question of bulk, ordinary unprepared turf, if properly dried, either in the open air or by artificial means, is more efficient than turf in any other form. Let a given quantity of turf be so worked up as to be reduced in point of volume, it certainly gains nothing in point of efficiency as fuel. On the contrary, I feel convinced that the process of pressing, as carried out at Haspelmoor, deprives the turf of some of its valuable component parts.

"'I am far from maintaining that no process is possible by which the difficulties connected with the use of turf on a large scale can be overcome; but I have little hesitation in saying that all the methods hitherto adopted with the object of reducing the bulk of turf, and facilitating its employment, have failed on the ground of expense.

"'This is indeed evident according to the memorandum (furnished by the administration of the State railways) of the relative cost of pressed turf and coal, viz., fl. 4 24 ks. to fl. 2 48 ks., or fl. 3 16 ks. respectively.

"'The expense of carriage of coal no doubt adds very considerably to its cost; but the pressed turf has also to be conveyed to the locality where it is used; and, as compared with coal, nearly a double quantity is required for supplying the engine, and must be carried on the tender.

"'When it is considered that in the carriage of coal from one locality to another for the use of the railways themselves, only the actual cost of the carriage, and not the tariff rate, can be calculated; when, also, the additional labour involved by the employment of turf, and the greatly increased expenses of warehousing are taken into account, it must be acknowledged that the advantages, in a financial point of view, of the turf fuel on railways in Bavaria are still problematical.

"'Looking at all the circumstances of the case, it is my opinion that pressed turf can only be used with advantage when it can be procured at somewhat less than half the price of coal. And if I am correct in this, it is certain that, with the methods of preparing or pressing hitherto practised, there are very few cases in which turf can compete with coal.'

"It would be seen from the foregoing observations that this gentleman's opinion, which certainly deserves due consideration, was less favourable to the use of turf as fuel for railway engines than might have been expected, looking at the results obtained on the State lines of Southern Bavaria. All the details given in this report have been derived from official sources, or have been officially pronounced to be correct.

"The mode of preparing the pressed turf, as practised at the Government establishment at Haspelmoor, in Southern Bavaria, is as follows:—

"The turf, instead of being dug from the moor in the ordinary manner, is cut up by means of a steam plough, the horizontal shares of which enter but a short depth below the surface, thus removing only the upper and drier portion of the turf. By this operation the turf is broken up into small fragments, and the fibres are thoroughly severed, by which the process of drying is greatly facilitated. The turf thus cut from the surface is moved and turned at intervals; it is then gathered into large heaps; and, after remaining exposed to the air and sun for some days, until dry, is removed to the manufactory. It is scarcely necessary to state that the operation of cutting and gathering the turf is only performed during the summer months. Arrived at the manufactory, the turf is passed through sieves having holes a square

inch in size, by which the large pieces of turf, the roots, and the tufts of grass are retained. The small turf which runs through the sieves is made to fall into a pit, from whence it is raised to the upper floor of the building by means of two sets of apparatus, similar in their construction to dredging machines; that is to say, a system of buckets made to revolve by means of a large wheel. The turf, as raised by the two sets of apparatus, is thrown from the buckets into the mouths of two cylindrical sieves, made of wire network, placed parallel one to the other. These sieves are 6 feet long, 3 feet in diameter at the upper end, and 2 feet in diameter at the lower end, and both ends are open. These are not fixed horizontally, but at such an angle as to present a fall of $1\frac{1}{2}$ foot in their length of 6 feet. They are set in motion by the steam-engine, and are made to revolve on their own axes, one towards the other. The turf goes through a second process of sifting, all the particles passing through the network of the cylindrical sieves as they revolve. From the sieves the turf, almost in the form of powder, is received upon an inclined plane, down which it falls into a trough a foot wide. This trough is provided with a snake screw, set in motion by the steam-engine, which, as it revolves, pushes the turf powder forwards towards an opening at the end of the trough, through which it falls into the drying oven below.

"The larger pieces of turf, which do not pass through the netting of the cylindrical sieves, slide downwards till they reach the lower end of the cylinder, where, in the same manner as the powdered turf, they are received on an inclined plane, fall into a trough provided with the same description of screw apparatus, and are pushed forward to the end of the trough into a receptacle near the furnace of the steam-engine, for which they serve as fuel.

"The drying oven is built of bricks. It is 15 feet broad, 35 feet long, and 14 feet high, divided into six storeys or floors. Each floor consists of a hollow box 2 inches in height, made of sheet iron; and all these hollow floors are so constructed as to communicate one with the other. The steam, which after each stroke of the piston escapes from the engine, is made to pass through the floors, and thus contributes towards the heating of the oven. In addition to this, a stream of hot air is conveyed into the oven by means of a pipe which passes under the furnace of the engine. By this arrangement the temperature of the oven is maintained at from 45° to 50° of Reaumur.

"On each floor is placed a series of screws working horizontally, which are set in motion by the steam-engine; and at the alternate

ends of each floor is an opening which communicates with the floor beneath, and the screws of each floor are made to work in an opposite direction to those of the floor immediately above it. The powdered turf falls from the trough above described into one end of the upper floor of the oven, and is pushed by the motion of the screws towards the opening at the opposite end. It falls through the opening, and is guided, by means of an inclined plane which projects from the wall of the oven a short distance below the opening, to the screws on the floor beneath; and by a repetition of this process it at last arrives at the farther end of the lower floor. The time occupied by the powdered turf in thus passing over all the six floors of the oven is about an hour; and in the course of its passage it acquires a degree of heat of about 40° Reaumur; but it is not completely dried thereby, as, on leaving the oven, it still contains from 10 to 12 parts of moisture. In this condition, however, it can be pressed with advantage. The steam which rises from the turf powder, in the course of its passage through the drying oven, is carried off by means of chimneys leading to the open air. From the lower floor of the oven, the turf powder falls into a large iron funnel; and from this it passes into four smaller funnels, each of which communicates with and feeds one of the presses. Of these there are four. They are ordinary eccentric presses, very strong, but of simple construction. Only three of the four presses are kept constantly at work at the Haspelmoor factory, the other being reserved for use in case one of the three gets out of order. All four are placed in one row, side by side, on the ground floor; and they are set in motion by the main shaft of the steam-engine, which shaft has a diameter of half a foot. For each press the main shaft is provided with a fly-wheel weighing 80 Bavarian centners (123½ lbs. avoirdupois each), a driving-wheel 1½ foot in diameter, and weighing 12 centners, and two rollers. The following is the mode in which the press works:—The main shaft being made to revolve by means of the upper roller, the driving-wheel turns a spur-wheel, having a diameter of 3 feet, and weighing 15 centners. The spur-wheel turns a shaft, on which it is fixed. The latter shaft is not common to all the four presses, each press having its own shaft. On this shaft is fixed the eccentric cylinder, which moves the piston-bars, of which there is one on each side of the press. The piston-rods are 5½ feet long, and have at the farther end a massive tail-piece, which moves backwards and forwards in a space or groove. To the fore part of the tail-piece is fixed the piston of the press, the end of the latter being shod with a steel plate 1 inch thick.

The two piston-rods, the tail-piece, and the piston itself weigh together 38 Bavarian centners. The box of the press, in which the piston moves horizontally backwards and forwards, is made of cast iron, and is of one piece. It weighs 55 centners. The top, or lid, of the press is detached, and can be screwed down more or less closely by means of a screw. The dimensions (breadth and depth) of the piston and of the cavity of the press are the same as those to be given to the cakes of turf when pressed, namely, 7 inches in breadth and 3 inches in depth. Above the cavity of the press, and communicating with it, is placed a funnel, into which the powdered turf falls when it leaves the funnel described above. At each backward movement of the piston of the press, the turf falls from the funnel into the cavity in front of the piston, and by the forward movement of the piston the turf powder is pressed into a solid brick. As the bricks of turf are pressed, they are pushed forward through a tube, till they arrive at the mouth of another tube, whence they fall by their own weight into the truck which carries them away. The piston performs from 42 to 45 movements per minute, by each of which a brick of turf is pressed. The weight of the bricks varies somewhat, according to the quality of the turf; but three-quarters of a Bavarian pound[1] is the average weight of those made from Haspelmoor turf. Each press would therefore produce about 30 lbs. weight of pressed turf per minute. This, supposing the three presses to be kept at work for twenty hours per day during three hundred days of the year, would give a total production for twelve months of 324,000 Bavarian centners (about 17,858 tons English)."

[1] The Bavarian pound weighs 1 lb. $3\frac{2}{4}$ oz. avoirdupois.

May 19, 1874.

The Session was concluded by a Conversazione, which was given by the President and Mrs. Harrison, in the West Galleries of the Annual International Exhibition Buildings at South Kensington, by permission of Her Majesty's Commissioners for the Exhibition of 1851. The section of the Exhibition opened to the visitors included the machinery in motion—this year principally devoted to wood-working and stone-dressing apparatus—and the Fine Arts Galleries. Some objects from the Scientific Inventions Court were transferred to the West Galleries, and a few models of special interest were contributed for the occasion by various members of the Institution. In addition to the members of all classes of the Institution, invitations were sent to, and were accepted by, a numerous circle of distinguished men of science and others; and in every case the card of invitation admitted a lady.

APPENDIX TO ANNUAL REPORT.

MEMOIRS.

CHARLES LOUIS NAPOLEON BONAPARTE, ex-Emperor of the French, was born in Paris on the 20th of April, 1808, and, after a career almost unexampled in its alternations between imperial splendour and nameless obscurity, died at Chislehurst on the 9th of January, 1873.

Of the eventful life which culminated in his grasping the sceptre of France, it is not necessary here to speak. It will suffice, in a few words, to state the grounds of his connection with this Institution. The late Emperor was, for some years—viz., from 1838 to 1840, and from 1846 to 1848—domiciled in London, and, as is well known, served as a special constable in King Street, St. James's, during the Chartist riots. During this time he frequently attended the meetings of the Institution, and on one occasion took part in the discussion arising out of Mr. Glynn's Paper "On the proposed Canal between the Atlantic and the Pacific Oceans,"[1] his speech exhibiting considerable practical knowledge of the conditions necessary for the success of such an undertaking. But his chief claim for recognition among engineers was his knowledge of the science of artillery, the manufacture of which, on other principles than those of the rule of thumb, was at that time beginning to attract the attention of the profession. The associations thus engendered were not forgotten on the part of the Emperor; and after the lapse of more than twenty years, he was recommended for admission into the Institution "because of his scientific acquirements, his professional knowledge as an artillerist, and his enlightened support of public works in all parts of the world," and on the 23rd of March, 1869, was elected by acclamation an Honorary Member. It is usual in such cases for a deputation of the Council to wait upon the newly-admitted member to obtain his signature to the Register of the Corporation. In accordance with this custom, Mr. Gregory, the Pre-

[1] *Vide* Minutes of Proceedings, Inst. C.E., vol vi. p. 427.

sident, accompanied by Messrs. Bidder, M'Clean, Cubitt, Hemans, and Manby, proceeded to Paris to present the diploma of election. The Emperor received the deputation most graciously, and requested that his sincere thanks might be conveyed to the members of the Institution for the honour conferred, and expressed his gratification at being elected a member of such a body. The cordiality which marked the official reception, and the special and even friendly hospitality which followed it, showed that the compliment was warmly appreciated. But the connection so begun was not destined to last long, and the stirring events that speedily followed prevented the Emperor from taking any further part in the proceedings of the Society. At Chislehurst, towards the close of his life, he avoided intercourse with the outer world, and lived so much in seclusion that his doings had ceased to excite public attention, and it was only his death that for a time re-awakened the interest felt in his wonderful career. The news was officially communicated by the President to the members of the Institution at one of the weekly meetings, when it was resolved that an address of condolence should be sent to the Empress. This having been suitably engrossed, and the common seal of the corporation attached, was most graciously received, the Empress instructing her Secretary to say that she was deeply touched by the sympathy of the members.

The Emperor Napoleon was born seemingly to greatness, and seemingly it threatened to elude him. "He struggled after it in the face of adverse circumstances from the time he attained to years of discretion. He partly achieved it, partly had it thrust upon him, and, after a success which should have satisfied his wildest dreams, he ended his active life in exile, as he had begun it." The one great characteristic that influenced his whole life was his intense veneration for the founder of his dynasty. He had an almost superstitious faith in the name of Napoleon. But, unlike his uncle, he was not cast in the mould of heroic conquerors. He was cold, calculating, cautious even to the extreme of moral timidity, and it is possible that this excessive caution, though it served him well while biding his time for the assumption of imperial power, may have contributed in no small degree to his downfall. From beginning to end his action in the fatal struggle with Germany was marred by a want of confidence that too plainly showed itself in his communications with his government. The famous "all may be re-established," that followed the defeats of Wörth and Forbach, showed how conscious he was of moving in

the shadow of the approaching ruin. As might be imagined from the vicissitudes of his career, few men showed stranger or subtler contrasts in their nature. "He owed his rise to the unflinching resolution with which he pursued a fixed idea; yet he hesitated over each step he took." He possessed undoubted abilities and some extraordinary gifts, but he certainly owed much to fortune; and so great was his confidence in her favours that he drew recklessly on his prestige, instead of husbanding it against evil days. "Had he been born in a station beneath the influence of those ambitions that tempt men to become criminal, he would have lived distinguished and died esteemed."[1]

Mr. WILLIAM JOHN FORREST, the third son of Mr. John Forrest, of Annan, Dumfriesshire, was born on the 18th of July, 1828. He received his early education at Annan Academy, and attained considerable proficiency in classics and mathematics. He subsequently spent some time in perfecting himself in mathematics under private tuition, and early in the year 1846 was articled for five years to Messrs. McCallum and Dundas, Civil Engineers, of Edinburgh. Whilst with them he was employed on the surveys of the Ayrshire and Galloway railway, and on the construction of the Edinburgh branch of the Caledonian railway.

In January 1852 he was appointed one of the assistant engineers of the Great Western railway of Canada, then in course of construction under Mr. R. G. Benedict, of U.S., as Chief Engineer. In 1853 he became chief assistant to the late Mr. James C. Street, M. Inst. C.E., who superintended the construction of the Hamilton and Toronto railway as Engineer for the English contractor, Mr. George Wythes, Assoc. Inst. C.E.; the company's chief engineer being Mr. George Lowe Reid, M. Inst. C.E. On the completion, in 1856, of this line (for which Mr. Forrest had prepared all the working drawings), he was employed for upwards of two years as chief assistant on the surveys and plans of the projected Niagara and Detroit Rivers railway, of which Mr. Street was the chief engineer. Towards the end of 1859 he returned to England, and subsequently, in 1863, joined the firm of Messrs. Street and Marmont, MM. Inst. C.E., and remained with them as chief assistant until the death of Mr. Street, in April 1867. He then continued in practice on his own account till the summer of 1869, when he returned to Canada

[1] "The Times," Jan. 10, 1873.

and became principal assistant to Mr. Sandford Fleming, M. Inst. C.E., the Engineer-in-chief of the Intercolonial railway. His duties in this office were mainly to superintend the preparation, under Mr. Fleming, of the designs and working plans of the numerous and varied structures in timber, stone, and iron required for that important line of railway. He acquitted himself in that post with great professional skill and judgment, and earned the well-merited esteem and respect both of the Engineer-in-chief and of the Dominion Railway Commissioners. He continued to hold this reponsible situation until his death; but he was obliged to relinquish active work in May 1873, having been seized by an attack of pleurisy of a severe character, from the effects of which he never fully recovered. He spent the summer at Kamouraska, on the lower St. Lawrence, in the hope of recovering his health; but whilst making a tour of inspection of some of the works of the Intercolonial railway, he was suddenly prostrated by illness and carried back to Kamouraska. There he rallied a little, but only for a brief space, for he breathed his last at that place on the 9th of September, 1873, and was buried at Ottawa.

Mr. Forrest was a clever engineer, but he was not fortunate enough to enjoy many opportunities of displaying his skill as an Engineer-in-Chief. He was a man of a high sense of honour, and was ever most jealous of the interests and fair fame of his profession, to which he was ardently attached. He was elected a Member of the Institution of Civil Engineers on the 2nd of March, 1869, and was also a Member of the Institution of Mechanical Engineers.

Mr. JOHN ROBINSON McCLEAN, M.P., F.R.S., &c., was born at Belfast, in the year 1813. After receiving a good general education, he studied at the University of Glasgow, with the intention of qualifying himself for the profession of Civil Engineering. About the year 1838 he entered the office of Messrs. Walker and Burges, by whom his talents were soon duly appreciated. He was actively employed on some of the large works under their direction, particularly upon the improvement of the Birmingham Canal, where he exhibited great engineering talent and skill, as well as fertility of resource. But he more especially displayed qualities which gained many friends, who at a future period gave that effectual support which carried him forward in his successful career. He subsequently acted for the firm as Resident Engineer on several important works, where, by attention and skill, he so distinguished himself, that Mr. Walker, desiring to retain his services, made him seemingly most advantageous offers; but,

acting on the judicious advice of an attached friend, he determined to start on his own account in London, and at the end of a year found success was assured.

Mr. McClean's professional engagements became eventually varied and extensive, as will be apparent from a glance at the names of some of the enterprises with which he became connected. Among the earliest of his important works were the South Staffordshire railway and branches, followed by the Birmingham, Dudley, and Wolverhampton line, traversing Birmingham by a double tunnel. Then came the system of the Furness railways, of which he was the Engineer-in-chief. This led to the numerous great enterprises of the Barrow-in-Furness district, including the harbour, docks, and railways, with all which Mr. McClean maintained his connection as long as he continued to practise professionally. He was also interested in the iron and steel manufactures of the district.

In 1849 plans were invited by the Metropolitan Commissioners of Sewers for the complete drainage of both sides of the Thames. In answer to this, one hundred and sixteen designs were sent in, and among them one from Mr. McClean, which was designated by the Commissioners as "the best conceived and most practicable scheme submitted, characterised by a well-devised system of intercepting sewers, in determining the situation and course of which a careful and elaborate study of the levels has been made." On two consecutive years Mr. McClean introduced into Parliament a well-considered scheme for supplying the metropolis with water, principally by gravitation, from Henley-on-Thames; and although the water companies were successful in their opposition to it, they were shortly afterwards obliged by Parliament to remove their pumping stations from London to above Teddington Lock, to improve the quality of the water supplied.

In the same year Mr. McClean took into partnership Mr. F. C. Stileman, M. Inst. C.E., who had been engaged with him as assistant in the construction of the South Staffordshire railway, the Birmingham, Dudley, and Wolverhampton railway, the Staffordshire and Worcestershire Canal Reservoirs, and the South Staffordshire Waterworks, by which latter a very extensive district is supplied with water from Lichfield.

In 1851 Mr. McClean received instructions from the late Emperor Napoleon III. to report upon the practicability of introducing in Paris the English system of public baths and washhouses. His advice was sufficiently favourable to induce the construction, at the private expense of the Emperor, of some extensive buildings

and machines, in which he was assisted by the late Mr. John Manby, M. Inst. C.E., long resident in Paris.

About the years 1854 and 1855 M. Ferdinand de Lesseps repeatedly visited England, for the purpose of resuscitating the scheme of cutting through the Isthmus of Suez, and, by means of a canal, to give a direct communication for large vessels between the Mediterranean and the Red Sea, so as to facilitate the voyage to India and China. The project had been examined in 1840 by Linant Bey and Mougel Bey, French Engineers in the Egyptian service, and then by M. Paulin Talabot, M. de Negrelli, and Mr. Robert Stephenson—the latter personally traversing the Isthmus—and, by the careful levelling and survey made under their direction by MM. Bourdaloue, Enfantin, and assistants, the identity of level of the two seas was established. This fact caused the abandonment at the time of the project, and induced the conviction that although the canal could be executed without difficulty, there were circumstances connected with it which would render the undertaking commercially unprofitable. M. de Lesseps, however, with his usual indomitable energy, suggested the nomination of an International Commission, composed of some of the leading Engineers of England, France, Austria, Italy, Spain, and Holland,[1] to visit Egypt, for the purpose of examining the localities, and of advising H.H. Said Pacha, then Viceroy of Egypt, on the project. M. de Lesseps sought aid in this country, when Mr. Rendel and Mr. McClean were nominated commissioners, and Mr. Charles Manby, the then Secretary of the Institution of Civil Engineers, was appointed one of the secretaries; but, from circumstances, Mr. McClean alone could proceed to Egypt at that

[1] "La Commission Internationale pour le percement de l'Isthme de Suez est composée de: M. F. W. Conrad, Ingénieur en chef du Water-Staat, à la Haye; M. Harris, Capitaine de la Marine Britannique des Indes, à Londres; Jaurés, Capitaine de Vaisseau de la Marine Impériale de France, et Membre du Conseil de l'Amirauté; M. Lentze, Ingénieur en chef des travaux de la Vistule, à Berlin; M. Lieussou, Ingénieur Hydrographe de la Marine Impériale de France, à Paris; M. J. R. McClean, Ingénieur Civil, à Londres; M. Charles Manby, Ingénieur Civil, à Londres; M. Montesino, Directeur des Travaux publics, à Madrid; M. De Negrelli, Inspecteur-général des Chemins de Fer de l'Empire d'Autriche, à Vienne; M. Paléocapa, Ministre des Travaux publics du Royaume de Sardaigne, à Turin; M. Renaud, Inspecteur-général et Membre du Conseil-Général des Ponts et Chaussées de France, à Paris; M. J. M. Rendel, Ingénieur Civil, à Londres; M. Rigault de Genouilly, Contre-Amiral de la Marine Impériale de France, à Paris. M. Conrad, Président; M. Barthélemy St. Hilaire, M. Lieussou, et M. Charles Manby, Secrétaires."—*Vide* "Percement de l'Isthme de Suez, documents publiés par M. Ferdinand de Lesseps." Troisième série. Paris, 1856.

time. On the return to Europe of the Commissioners, it was resolved that the results of the local investigation should be reported upon by a scientific commission at Paris. This was attended by Mr. McClean and Mr. Manby, when, as the reports show, they both dissented from most of the conclusions of the majority. Recent events have proved that the opinions formed by Mr. McClean, on his first visit to Egypt, as to the commercial prospects of the undertaking, were substantially correct.

In the course of his professional career Mr. McClean, among other works, became connected with the Birmingham Canal Navigation, the Bute Docks, the Cardiff Docks, the Alexandra Docks (Newport), the Surrey Commercial Docks, the Tottenham and Hampstead Junction railway, the Bristol and Portishead Pier and Railway, the Eastbourne Water and Sewerage Works, and many others. He was also extensively consulted upon foreign works, and was Consulting Engineer of the system of railways in Galicia and Moldavia, for which the late Mr. Brassey was the contractor.

In 1861 he was appointed one of the Royal Commissioners for examining and reporting upon the numerous plans submitted for the Thames Embankment—a project to which he was always very favourable. In 1862 and 1863 he again acted on Royal Commissions for the extension of the Thames Embankment; and in 1865 upon the Royal Commission appointed for the investigation of the Cattle Plague, upon which he expressed some sound original views. In the latter year he was also appointed one of the Royal Commission on Railways.

On the decease of Mr. James Walker, in 1862, several Government appointments which became vacant were offered to and were accepted by Mr. McClean, who thus became the Engineer to the harbours of Dover, Alderney, and St. Catherine's, Jersey; with the Breakwater and the Shovel Rock Fort at Plymouth—most of which positions he held until the year 1868, when he retired from the active duties of the profession, on entering Parliament as Member for the Eastern Division of Staffordshire. He had previously, in 1857, in conjunction with Mr. G. F. Ferguson, unsuccessfully contested Belfast against the present Lord Cairns and Mr. Richard Davison. Henceforth he took more leisure. He travelled much, visiting Egypt several times. At last he unfortunately determined to make a longer journey, to India, China, Australia, &c.; but whilst in India he received a sunstroke, which necessitated his return to England, and from the effects of which his health never completely recovered.

It should not be omitted to be mentioned that Mr. McClean took an active interest in ocean telegraphy, and was for some time Chairman of the Anglo-American Telegraph Company. He was a Fellow of the Royal, the Geological, the Astronomical, and other scientific societies.

Mr. McClean was elected a Graduate of the Institution of Civil Engineers on the 12th of February, 1839; in June 1844 he became a Member by transfer; in 1848 he was elected a Member of Council, in 1858 one of the Vice-Presidents, and in the years 1864 and 1865 he occupied the Presidential Chair. In his able inaugural address, which attracted considerable attention, he demonstrated very forcibly the direct bearing of Engineering work upon the general prosperity of the country. He was warmly attached to the Institution, and never omitted any opportunity of being useful to it, or of impressing upon the world the benefits which it was calculated to confer upon society. He also took great interest in the creation of the Benevolent Fund of the Institution of Civil Engineers, and employed his influence as President to secure the adoption of that admirable project.

For more than thirty years Mr. McClean occupied a prominent position in the profession of which he was an ornament, not only from his talents, but from his uniformly upright, conscientious conduct. His decease occurred at Stonehouse, Isle of Thanet, on the 13th of July, 1873. Esteemed as a public man and beloved as a friend, his loss was deplored by a wide circle, whilst there are many who will miss the kindly, generous acts so unostentatiously and so delicately performed by him.

Mr. CHARLES NIXON was born in London, on the 2nd of June, 1814, and was educated at a private school at Brighton. His father, Mr. William Nixon, an architect and surveyor, was engaged in superintending the erection of the Royal Pavilion at Brighton, and of Buckingham Palace, up to the time of his death. Mr. Charles Nixon commenced his professional studies in the year 1832, under Mr. John Nash, the architect, upon whose death, in 1835, he was engaged as an assistant to Mr. William Ranger, a contractor for several extensive engineering works. Among other duties he was intrusted with the superintendence of the new graving docks then building in Her Majesty's Dockyards at Chatham and at Woolwich, and afterwards of a length of 7 miles of the Great Western railway, which comprised a stone bridge over the floating harbour at Bristol, a bridge over the River Avon, five tunnels, and a stone viaduct of forty arches. The contract for the latter works

having been abandoned by Mr. Ranger, it was taken up by Mr. M'Intosh, by whom Mr. Nixon was retained, and he continued to have charge of the whole of the works of this portion of the Great Western line. On their completion he further superintended for Mr. M'Intosh the construction of that portion of the London and Greenwich railway between Deptford and Greenwich, the entire length of which is a viaduct, and includes the large lifting bridge over the River Ravensbourne. In the year 1841, on the completion of these works, he obtained an engagement with Messrs. Walker and Burges, and superintended for them the widening and securing of the foundations of old Westminster Bridge, a work of great engineering difficulty. He was also intrusted with special surveys and inspections of works, including among others the new harbour and docks at Jersey, old Blackfriars Bridge, &c. From long practical experience, and under the advice of the late Mr. James Walker (Past-President Inst. C.E.), he was induced to enter into business as a Civil Engineer in 1845, and immediately became engaged by the Directors of the Boston and Midland Counties Junction Railway Company to make the surveys for that line.

In 1846 the Chairman of the Cork and Bandon Railway Company was deputed to consult the late Mr. Brunel (V.P. Inst. C.E.) and Mr. Walker as to the appointment of an Engineer in Chief to the Company, when they recommended Mr. Nixon in the strongest terms, as a man of experience in railway construction. Under engagement with the Company, he constructed the first railway tunnel in Ireland, and at the same time he built skew bridges of large span of ordinary rubble masonry. These new and difficult works were executed economically, although exclusively by miners, masons, and excavators from the locality, who were almost entirely trained by himself with the aid of his principal assistant, Mr. Ronayne, M.P., M. Inst. C.E.

He was also appointed Engineer in Chief to carry out the Waterford and Kilkenny railway; and among other matters he was engaged in making the surveys and obtaining an Act for constructing what is now called the Kilkenny Junction railway, from Kilkenny to Maryborough, where it joins the Great Southern and Western (Ireland) railway; in preparing plans and designs for the reclamation of about 10,000 acres of land in Castlemaine Estuary, in the county of Kerry, for which he obtained an Act in 1852; in laying out lines of railway to the harbours of Crookhaven and of Bantry Bay, and in reporting upon those harbours as ports of call, and upon the communications with them.

During the time he lived and worked in Ireland, although an Englishman and a stranger, he was trusted and respected by all who knew him, but particularly by the working men, and whatever might be their complaint, on an appeal, his decision always settled any dispute. He returned to London in the year 1853, and was engaged upon a large number of arbitration cases.

In 1858 he entered into partnership with Mr. William Dennis (M. Inst. C.E.), who had been his chief assistant for some time, when they became jointly engaged in many undertakings, among which may be mentioned the Faversham Water-works, the Tunbridge Wells Water-works, the Parsonstown and Portumna Bridge railway, the Cwmorthin Wharf and tramways, &c. This partnership was terminated in 1869, after which his professional career was pursued alone. One of the last matters that engaged his attention was the better supply of water to the town of Bridgwater, for which he obtained an Act in 1871, but he did not live to see the works carried out.

He was elected an Associate of the Institution on the 1st of February, 1842, and in the same year contributed a Paper on the tunnels situated between Bristol and Bath, on the Great Western railway,[1] for which he received a premium of books. On the 6th of March, 1855, he was transferred to the class of Members, and for many years he attended the Meetings, and took part in the discussions. He suffered from delicate health almost throughout life; but, notwithstanding this, he was a most indefatigable worker. He died on the 22nd of July, 1873, after a lingering illness, at Clapham, Surrey, in the sixtieth year of his age; and his remains were interred in Kensal Green Cemetery.

Mr. DANIEL BADDELEY PRITCHARD was born in July 1827, at Edgbaston, near Birmingham. His father, Mr. Daniel Pritchard, was a contractor for public works, and one of the first railways in England—that from Wigan to Parkside—was made by him. The elder Pritchard was also engaged on the Harecastle Tunnel, under Telford; and subsequently undertook No. 3 general contract on the London and Birmingham railway, and various other contracts in different parts of the kingdom. On these different works the younger Pritchard underwent a regular system of training as an engineer. To acquire further experience, he was afterwards placed for about twelve months with Messrs. James Horne and Co., who were then carrying out the Crown Street Tunnel

[1] *Vide* Minutes of Proceedings Inst. C. E., vol. ii., Session 1842, p. 138.

and Lime Street Extension, Liverpool. Subsequently he was successively engaged for about two years by Messrs. John Taylor and Co., upon the Swansea contract of the South Wales railway, as engineering representative, in setting out, measurement of the work, &c.; for one year and a half under the late Mr. James Potter, M. Inst. C.E., on the Sheffield and Lincolnshire railway; and for about six months on the Garston Branch railway, near Liverpool. Having thus practically learnt the profession, and not finding sufficient scope at home, he determined to try the colonies. He selected Australia as the field for future practice, and landed at Melbourne in 1852. Almost immediately on arrival he was appointed to superintend the construction of the first railway in Victoria, viz., that from Melbourne to Hobson's Bay, which, though but a short line, was one of great importance, as connecting the metropolis of Australia with its port. After being for about two years in the service of this railway company, he set up on his own account as a Civil Engineer at Ballarat, then at the height of the gold fever. Here, among other things, he surveyed and estimated for projected extension lines of railway from Ballarat to the western districts of Victoria, in continuation of the present Government railway from Melbourne to Ballarat. He also made the gas-works dock, several timber bridges, &c.; but his attention was more exclusively directed to mining. He became the manager, in the year 1862, of the Black Hill Quartz Crushing Company's works, and erected the new battery of sixty stamps, with other powerful machinery, opened out the extensive mine, and successfully worked this, the largest, mining plant then in Victoria, for seven years. On leaving, he was presented with a handsome testimonial, in the form of a silver tea-service. During these years he also acted as Consulting Engineer to several other mining companies in Ballarat. Finally, he established himself in Melbourne, as a Civil and Consulting Engineer, and obtained an excellent practice, being frequently consulted in reference to mines in other colonies, as Adelaide, Tasmania, &c. He had just accepted an engagement with three mining companies in New South Wales, to set out and furnish plans for the erection of their works, and to give an opinion on the capabilities of the mines, when his sudden death occurred in Sydney, through an accidental fall, on the 8th of September, 1872, at the comparatively early age of 45. He lies buried in the new cemetery at Haslem's Creek, near Sydney, six hundred miles away from his own home.

In his immediate circle the news of Mr. Pritchard's death was received with great regret. He had not long previously assisted

to establish "The Australian Mechanic and Journal of Science and Art," the editor of which periodical, in an obituary notice, bears the following high testimony to his character as a man who "was peculiarly straightforward and upright in all his transactions; he was earnest and practical in thought, skilful in action, of high integrity, and honest in feeling. His reports on scientific questions were masterpieces of conciseness."

Mr. Pritchard was elected a Member of the Institution of Civil Engineers on the 7th of February, 1865, but his constant residence in Australia prevented his taking any part in its proceedings.

Mr. ALEXANDER SAMUELSON, fourth surviving son of the late Mr. S. H. Samuelson, was born in Hamburg on the 20th of July, 1826. His father returned to England in the following year, and he received his school education at Hull and at Liverpool. At an early age he was placed in the works of Messrs. Jones and Potts, of Newton, who were at that time chiefly engaged in the construction of locomotive engines, and at the age of fifteen he was apprenticed to Messrs. Bury, Curtis, and Kennedy, of Liverpool, Mr. Bury being then the contractor for locomotive power on the London and Birmingham railway. On the conclusion of his apprenticeship he entered the works of Messrs. Nasmyth, Gaskell, and Co., of Patricroft, where he took part, under the direction of Mr. James Nasmyth and Mr. Wilson, in the designing of the steam hammer, which was occupying Mr. Nasmyth's principal attention. In the year 1845 Mr. Samuelson entered the works of Messrs. Boulton and Watt, of Soho, and was employed in designing the atmospheric pumping engines for the South Devon railway, and in other important works. Ill health obliged him to resign this appointment, and in 1848 he undertook the management of the agricultural implement works at Banbury, now the property of his brother, Mr. B. Samuelson, M.P. In 1854 he became a partner in the engine and shipbuilding works of his brother, Mr. Martin Samuelson, at Hull, and took an active part in the various contracts, including the building of many oil-crushing mills, and of steam and sailing ships for the Baltic, Indian, and American trades. In 1861 the partnership was dissolved, and Mr. Samuelson removed to London, where he practised as a Consulting Engineer, his time being engaged chiefly in the superintendence of the construction of machinery, in the valuation of engineering plant, and in giving evidence before the courts on questions involving mechanical knowledge. He was, however, also associated with Mr. Brunlees in

the preparation of estimates for a second direct line between London and Brighton, and was appointed by Vice-Chancellor Malins one of the official liquidators of the Imperial Land Company of Marseilles. In the summer of 1873 excessive application to his professional duties brought on symptoms of disease, which he unfortunately disregarded, until a fit of fainting with which he was seized during his summer holiday at Folkestone revealed the existence of heart disease. His anxiety to fulfil the duties of his office in the liquidation of the Marseilles Land Company induced him to break in upon his holiday, and to leave Folkestone for Paris. On the 4th of September he arrived there in apparently good health; but in the course of the same evening he became hysterical, and expired suddenly at the Hotel Westminster whilst the medical attendant who had been sent for was preparing a night draught for him at a neighbouring chemist's. His remains were removed to England, and are interred at Kensal Green.

Mr. Samuelson was elected a Member of the Institution on the 1st of April, 1862. He was also a Member of the Institution of Mechanical Engineers, and of the Institution of Naval Architects. He was one of the original promoters of the volunteer movement in Hull, and held the rank of captain in the East Riding of York Volunteer Artillery under his brother, Mr. Martin Samuelson, as lieutenant-colonel.

Mr. JOEL SPILLER was born in the year 1790 at Buckland Brewers, North Devon. While yet an infant his parents removed to Exeter, in which city the first twenty years of his life were spent; but as the metropolis was at that time considered the only place likely to afford an opening for an enterprising youth, thither, in 1810, young Spiller made his way. He appears to have begun the real business of life under the late Sir Marc Isambard Brunel, M. Inst. C.E., in whose celebrated saw and veneer mills at Battersea Mr. Spiller was employed as an assistant. While here, he was specially entrusted with the manufacture of crystallized tin-foil sheets, which were largely used for ornamental purposes. The process as carried on by Sir M. I. Brunel was a secret one, and Mr. Spiller was the only operative to whom the method of production was known. He remained at the Battersea Mills until they were burnt down, about the year 1814, when he set up for himself, at first on the Middlesex side of the River Thames, but soon afterwards, he removed to Battersea, where for forty years he carried on the business of a millwright and engineer.

On the 24th of September, 1835, he took out a patent (No. 4,916) for machinery to be employed in the working of pumps. In France at that time the manufacture of sugar from beetroot was a very extensive one. Mr. Spiller supplied most of the machinery required, and these "differential pumps" were in all cases adapted to the hydraulic presses for extracting the juice from the pulp. The application was as follows: Supposing two wheels to be geared together, one having a hundred, and the other one hundred and one teeth. On the face of each wheel there was a crank-pin working a similar force-pump, one foot and delivery valve serving for both pumps. At the first rise of the ram of the press, the two crank-pins occupied such a relative position that both force-pumps descended together, and discharged the combined volume of their plungers into the press. After a revolution of the wheels, one plunger would be the hundredth part behind the other in its stroke, and this diminishing action continued till at last one plunger came to the top of the stroke and its fellow at the bottom. At this point, of course no water would be discharged by the pumps; but then the ram of the press had reached the limit assigned for compression. By this curious action the desired effect was obtained of proportioning the quantity of water to the force of compression required, the full volume of the pumps being thrown at the beginning of the rise of the ram, which diminished to nothing at the end. Mr. Spiller was also engaged, in conjunction with the late Mr. Barnes, on works in connection with the River Seine. While in France he was much pressed to remain and be naturalized, and a lucrative offer of partnership was made to him; but the French mode of life not pleasing him, he declined to surrender his birthright, and elected to remain an Englishman.

Mr. Spiller's name is, however, principally associated with the establishment of steam navigation on the River Thames, especially for the above-bridge traffic, between Putney and London, to which his attention was turned as early as the year 1832. Clearly foreseeing that the cumbrous marine engine then commonly in vogue was not adapted to the small boats which alone could perform the proposed service, all his energies were directed towards contriving a more compact arrangement of the necessary machinery. His friends were subsequently informed that a steamboat could be constructed which should be capable of navigating the shallow water of the Thames at all times of the tide at a good speed, and with ample accommodation for passengers. Being encouraged to persevere, he constructed, upon the model of an eight-oared boat in possession of the Leander Rowing Club of London, his first

steamboat. This vessel was 65 feet long, 7 feet broad, and 4 feet deep, with raised cabins and engine-room, and was divided into three compartments. It was propelled by a pair of three-horse engines with oscillating cylinders, one condenser, and two air-pumps worked by an eccentric on the main shaft. The slides were of the short D type, worked by a rack and sector, fixed on a spindle; on this spindle there was a cross bar, having a pin at each end for the eccentric rod to work upon—the one pin being for the forward, and the other for the backward motion of the vessel,—the eccentrics being fast on the shaft. Steam was supplied from a common flued boiler with two furnaces, and the working pressure was 3 lbs. per square inch. The boat was christened the 'Star'; but, after repeated trials, she failed to satisfy the expectations that had been entertained, for the boiler did not generate steam sufficient to maintain the full pressure, and the speed was not so great as was anticipated. Upon testing various-shaped paddle-floats, some half-circular, some square, &c., the shallow parallelogram was found to be the most effective. A new vessel was laid down in 1833, about 75 feet long and 8 feet beam, with raised cabins as in the other. She was superbly fitted-up, and the charge was to be 1*s.* for each saloon passenger, and 9*d.* for each fore-cabin passenger, for every journey from Putney to London, or *vice versâ*. The engines were constructed with oscillating cylinders on the same model as the others, with some slight alterations. The boiler had oval copper tubes through which the fire passed, and the shell of the boiler was sufficiently strong to bear a pressure equal to 6 lbs. per square inch. This vessel was named the 'Fly,' and was licensed to carry one hundred passengers. The journey between Putney and London was performed, at low water, against the tide, in one hour and a half, including stoppages, and with the tide in one hour, and the boat made two 'down' and two 'up' trips every day. The greatest defect in this boat was the difficulty of maintaining steam at the increased pressure in the boiler, which often caused delay and annoyance to the passengers. This deficiency in the boiler gave Mr. Spiller considerable trouble and anxiety. He thought of the application of heat to the lower part of a square chamber filled with tubes of 1 inch diameter, the tubes having an inclination of about 3 inches per 1 foot in length from back to front. The effect was to cause the steam and heated water to rush to the top, and the colder stream to descend to the lowest point, thus producing a constant circulation, and obtaining a great heating surface in the smallest space possible. After several trials to ascertain the quantity of fuel consumed,

compared with the previous quantity, it was found to be one-third less. A new method was adopted of supplying air to the furnace, which was constructed to burn oven coke to obviate the smoke nuisance. The system was to rest the bottom of the boiler upon an air-tight box, with a small opening, in which was inserted a mouthpiece of a fan or blower, driven by an endless chain from the main shaft, over toothed wheels to prevent slipping, thus forcing a strong current of air through the furnace bars with great effect. This was a most important addition, and was completely successful. The steam could be maintained at full pressure, the weight was reduced by one-third, and the space occupied was reduced by one-half. The boiler was placed in the 'Fly' in the year 1834, and she was much improved in speed and a lighter draught obtained. At first everything was against the 'Fly.' The prejudice of the watermen was intense; no one would navigate the boats, and no waterman would take a passenger to or from them. However, the public support enabled Mr. Spiller ultimately to live down all opposition.

A patent was obtained for a boiler on this principle, which is thus described in the "Abridgments of Specifications relating to the Steam Engine," vol. i. p. 360, 1871:—

"A.D. 1835, September 24.—No. 6,897. Spiller, Joel.—Boiler. A 'tube chamber,' having the 'egress flue' or chimney at its upper part, is placed in the centre of the boiler, and beneath it the fire chamber and ash-pit. A number of straight tubes, about an inch in diameter, open at each end, are placed across the tube chamber, and passing through its sides communicate with the body of water within the casing surrounding them. They are placed in parallel rows, one row above another, leaving space between the rows and each tube for the free passage of the air around them; each tube and row lies at an angle with the horizon. The steam in ascending to the higher ends of the tubes draws a constant supply of water from their lower ends, and a rapid circulation is produced. A 'dashing plate' in the steam chamber prevents the rise of water with the vapour. For marine engines, a wind-fan may supply a current of air to the fire chamber."

In 1836, Mr. R. J. W. Leith and two or three friends started the London and Westminster Steamboat Company, the first of several companies which maintained a service of small passenger boats between London Bridge and various places higher up the river. The London and Westminster Company's steamers were known as the 'Flower Boats,' and ran from and to the Surrey side of Westminster Bridge. Of the original boats, five, viz., the 'Rose,' the

'Lily,' the 'Iris,' the 'Daisy,' and the 'Shamrock,' were engined by Mr. Spiller. The engines were made in various ingenious ways, mostly with the object of getting rid of the beam, and were supplied with steam by the patent tubular boilers before referred to. The pistons of these engines had metallic packings, then scarcely known or used in marine engines; but Mr. Spiller found that unless the springs for forcing out the segments were strong enough to resist the pressure of the steam, they were forced inwards, allowing the steam to pass. He then thought of making his piston packings act on the same principle as the cup leather of a hydraulic press or pump, so that the pressure of the steam itself should force the packing out against the cylinder. To effect this, the pistons were made in one casting—that is, without any separate top and bottom plate. Around the piston there were two broad grooves, separated by a solid part of the piston as a ring or mid-rib. The packing rings occupied the two outer grooves, fitting loosely, but being quite steam-tight on the mid-rib, being kept in contact therewith by a few springs. There was ample space left over the opposite packing rings for steam to get behind them to force them outwards. From their loose fit it was impossible that the packing rings could ever stick fast in the grooves. These pistons were found to work so excellently that Mr. Spiller continued to make them as long as he remained in business. The idea had not been published, and has been re-invented many times since.

The object of the tubulous boiler was to obtain steam of a comparatively high pressure (40 lbs. or 45 lbs.) without the danger of explosions, the recurrence of which had begun to give steamboats an unenviable notoriety. Mr. Spiller's views seem to have tended towards the employment of the compound principle, now so profitably applied in connection with the marine engine; but at this time he had not proceeded so far in his practice, and he confined himself to designing various modifications of detail in the single-cylinder engines then in use. The invention of the water-tube boiler was highly esteemed, other makers of marine engines eagerly adopting it, and paying Mr. Spiller the usual royalties. Though the water-tube arrangement has been superseded by the ordinary return-flue-tube boiler for river boats, owing doubtless to the difficulty of making the tube-connections tight in the case of large boilers, as well as of ascertaining in which tube a leak arose, and the necessity of letting down the pressure before a tube could be plugged, yet, latterly, the water-tube system has again been brought prominently forward, various expedients being resorted to in order to effect the due circulation of the water. In

one of the most recent of these arrangements, the principle is adopted of inclining the tubes at an angle with the horizon, thus reverting to Spiller's system of nearly forty years ago in its entirety.

A notable illustration of Mr. Spiller's prescience is afforded in the fact of his having, in those early days, built and worked engines with high and low-pressure cylinders on the principle of the modern compound marine engine. The credit of initiating this system has been publicly awarded to Mr. Spiller. Mr. F. J. Bramwell, F.R.S., M. Inst. C.E., in a Paper read before the Institution of Mechanical Engineers at Liverpool, in July 1872,[1] stated that "About the same time, but it is believed somewhat before the time of the 'Cricket,' Mr. Spiller, of Battersea, made a small river steamer, which ran for many years, with one high-pressure and one low-pressure cylinder." The boat thus referred to was called the 'Era,' and ran regularly between Putney and London Bridge. It was engined on the system of a Swede named Zander, and attracted considerable attention.[2] Another boat, termed the 'Sunbeam,' was built shortly afterwards, containing some curious novelties. The steam was worked at a high rate of expansion in single cylinders, which were steam-jacketed. The engines were of the 'steeple' kind, and actuated very large paddle-wheels. The boat lay low in the water, and its long, sharp bows and fine lines gave it an appearance of great speed. It was elegantly fitted up for passenger accommodation, and had a long career, its last appearance being some four or five years ago, when it was recognised performing the functions of a tug to a string of coal-barges, its dingy condition altogether belying its name. A shorter and a more dramatic career attended a rival boat. After the 'Era' and the 'Echo' had run without mishap for several years, the ill-fated 'Cricket,' which carried passengers from the Strand to London Bridge, at the charge of one halfpenny each, burst its boilers while taking in passengers at Hungerford pier, and caused great loss of life. It is fair, however, to record that the jury which sat on the bodies exonerated the maker of the engines, Mr. Joyce, of Green-

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[1] *Vide* "On the Progress effected in Economy of Fuel in Steam Navigation considered in Relation to Compound-Cylinder Engines and High-Pressure Steam." Proc. Inst. M.E. 1872. Page 130.

[2] A similar boat (the 'Echo'), built and engined by Mr. Spiller in 1841, worked to Richmond. The engines were on the Zander principle, and had one small cylinder (high pressure) and one large cylinder (low pressure) working on cranks at right angles. These engines worked very economically. The pressure used was 45 lbs. per square inch, then considered high.

wich, from blame in the matter, it having been proved to their satisfaction that the explosion was due to the action of the enginemen in overloading the safety-valve.

The engines of the 'Era' and the 'Echo' were entirely novel in their construction, embodied so many inventions from the ingenious mind of Mr. Spiller, and have been proved by years of effective working to be successful, that they may be recorded amongst useful discoveries unpublished. The steam was first worked in a small cylinder. From this it passed into an intermediate chamber, clothed with felt, of considerable capacity, in order to maintain a nearly constant pressure. From this chamber the steam was led into the large cylinder; from thence it was finally exhausted into a surface condenser. The cranks were set at right angles, and the areas of the two cylinders being duly proportioned to the relative pressure, the motion and power were thus equalised. The steam was worked expansively in the small cylinder, so as to bring the terminal pressure nearly down to that in the intermediate chamber, thus preventing loss from the sudden grade to a lower pressure. A curious feature of the intermediate chamber consisted in its being entirely filled with an immense number of minute trays, composed of strips of embossed copper. This was the main principle in Zander's patent. His theory was, that at the termination of the stroke of the high-pressure piston water would collect in these trays, to be evaporated on the first readmission of fresh steam at the commencement of the next stroke. However, no proof was obtained that any water ever did become deposited in this way; and Mr. Spiller had so little faith in these trays, that he often said the engines would be better without them.

Another novelty in these engines was the surface condenser, which had neither tubes nor packed joints. Each separate element of the condenser was made up of two large square sheets of thin copper; the edges of each of these were dished up to form a flange or rim, like an ordinary tray, one quarter of an inch deep, so that when placed together there would be half an inch between them. In order to prevent the sheets from collapsing by the pressure of the atmosphere, they were kept asunder by an assemblage of ½-inch copper strips, rolled or crimped in a zigzag or undulating form, and equally distributed over the plates. On account of this bending no tilting could occur, and the extent of the condensing surface was greatly augmented; for it was rightly considered that the conduction from the trued edges of these strips bearing on the outer cool plates would be equivalent to extra cold-water surface. There was a circular hole for the entry of the exhaust steam in the centre

of each plate, and between the two a gun-metal ring, half an inch thick, with a number of circumferential through holes. Everything being set in place, the two plates were lightly riveted together at the edges (the lap of the joints having previously been well tinned), and were finally fused together and made good with soft solder. The required number of these elements were united and put together by placing between them flanges or large gun-metal washers about one quarter of an inch thick, of the same inside and outside diameters as the internal ones. The joint was made tight on both sides with canvas collars, and the usual red and white lead. A strong rod was passed through the whole series, with screwed ends reaching through the bends of the elbows of the inlet and exit pipes, so that when the nut was tightened up all the flanges were brought together at once. This simple arrangement was placed to fit close on the opposite sides in a sheet-iron tank, the inlet above and the outlet below, and cold water from the circulating pump was caused to traverse through the quarter-inch spaces between the elements. As this ingenious arrangement had only one centre of connection and point of support, it was quite free from the irregular expansion so fatal to all joints; and during the many years that these condensers were under the knowledge of our informant[1] he did not hear of any leakage, nor were the condensers ever taken asunder for repair, and a high rate of vacuum was always maintained.

The marine engines herein referred to were run at a high piston speed for the sake of lightness of machinery; and in the 'Echo' the engine-shaft (with outside cranks) was geared down on to the paddle-shaft. A difficulty had, therefore, to be overcome in contriving an air-pump valve that would act quickly and without battering itself to pieces. The great success of the modern high-speed direct screw-propeller engines is due to the use of vulcanised india-rubber for the pump valves; but this material was unknown in those days, and metal had to be employed. In the large slow-going marine and land engines the old "butterfly," or flap valve, was nearly the only one in use. With rapid reciprocations this failed, and was quickly destroyed. The air-pump valves of Mr. Spiller were constructed as follows: The footplate and bucket were drilled through with a number of holes an inch or more in diameter. Each of these was covered by an independent valve, consisting simply of a thin turned disc of gun-metal. The rise of the series was limited to something less than half the diameter by an upper

[1] Mr. F. H. Wenham.

grating bolted to the piston. From this casting descended a number of pegs, close to and surrounding each disc in threes; these served as guides to keep them all in place. These pumps, after years of work, were proved to be very effective, prompt in action, and at the same time enduring, from the extreme lightness of the little valves.

These boats are thus referred to, as in them was shown the germ of a principle which has since developed to giant proportions in the steamers of the chief ocean navigation companies.

Many are the inventions and improvements that Mr. Spiller's clear-seeing eye and most fertile brain have given to the world, for which he never cared to gain either wealth or credit. "What matters it," he would say, "who did it, so that the thing is done?" Mr. Spiller claimed to have invented the 'sweep' or 'arch motion,' which enabled the eccentric to act on the valve without being influenced by the vibration of the cylinder. He is stated to have applied this principle to passenger boats, when it was perceived by the quick eye of an engineer passenger, who, observing "That's good," at once took the free gift, and the 'sweep' has since been generally adopted. There exists a difference of opinion as to this alleged circumstance, some engineers asserting that Mr. Spiller's boats were not fitted with oscillating engines; but Mr. William Milward says: "In 1869, Mr. Spiller showed me a letter, in Cardiff, which he had received from the late Mr. Joseph Miller, M. Inst. C.E., written from Philadelphia. Mr. Miller thanked Mr. Spiller for his invention of the 'sweep' motion in oscillating engines, and attributed his success to the use of Mr. Spiller's invention." Mr. Spiller's widow also states, that though, from her ignorance of mechanics, she is unable to recall the terms in which her husband stated the nature of his invention, yet that it was such as to render the oscillating cylinder available (or desirable) for marine engines, when it was not so without it.

Mr. John Bourne, so well known in connection with Indian steam navigation, writes: "I should be disposed to say, from what I remember of Spiller's boats, that his main merit consists in the introduction of small double engines, well proportioned and neatly made, and with small boilers on his principle, which were lighter than flue boilers. On the Clyde, at this time, the boats were uniformly larger, generally had single side-lever engines and flue boilers, and were less compendious and refined than Spiller's boats on the Thames."

On March 9, 1841, Mr. Spiller was elected a Member of the Institution of Civil Engineers, "because of his extensive engage-

ments as a Civil Engineer and as a manufacturer of steam-engines both in England and abroad, and because of his attainments in theoretical and practical science." He regularly attended the meetings, and frequently took part in the discussion of subjects with which he was familiar, such, for instance, as the resistance to bodies passing through water, Ericsson's caloric engine, &c. He made a series of careful experiments with screw propellers, at a time anterior to those of the late Sir F. P. Smith, but finding that the screw did not give such good results as the paddle, he gave up the idea, though unwillingly.

In 1850 Mr. Spiller patented an ingenious arrangement for cleansing and separating wheat. The machine was exhibited in the Great Exhibition of 1851, where he had the pleasure of explaining its action to the Queen and the late Prince Consort. This apparatus was employed in the last important work upon which he was engaged while at Battersea, a steam flour mill for his cousin, Mr. Joel Spiller, of Bridgewater. It was erected at Cardiff in 1853, and soon after, his cousin dying, Mr. Spiller went to take charge of the mill, selling his business at Battersea, and thereby severing the associations of forty years.

Mr. Spiller took a great interest in the science of horology. A love for it seemed to be innate, for in his boyish days he was fired with the desire "to make a real live clock;" and he managed to attain this object of ambition. Securing to himself some stray discarded bits of clockwork and metal, he day after day worked with untiring patience; then mounting a loft, reached only by a ladder, he proceeded to bring life to his creation. One day the father was asked to visit the loft, as there was something there to look at; and great was the boy's delight when, to the inquiry, "How came it there?" he was enabled triumphantly to reply, "I made it, father." This little anecdote, related by Mr. Spiller not long before his death, shows the bent of his early genius. On retiring from more active life he gave much time and thought to bring into practical working an idea for an escapement different in principle from any yet known. At length, after many trials came success, and, about the year 1860, one of the clocks to which the escapement was applied was tested by a transit, the result being a variation of only eight-tenths of a second in one hundred and twenty-eight days' observations taken three times. Publicity was to be given to this invention at the International Exhibition of 1862, but circumstances induced its withdrawal after a place had been assigned for it. His latest idea was to present one of these clocks to the Royal Observatory at Greenwich.

Towards the end of the year 1860 Mr. Spiller definitively left Cardiff, and, after five years' residence at Bridgewater, the last seven years of his life were spent in peaceful enjoyment at a retired country home, Salcombe Lodge, in the beautiful vale of Sidmouth, in his native county of Devonshire. When he had long passed the allotted span of human existence, so unbroken was his health, both of mind and body, that not only could he enjoy a walk to the top of one of the steep Devonshire hills, and work for hours together at the bench, but he wrote several able letters for publication, and still acted as a Consulting Engineer. He said he felt as capable of continuous thought as ever, and that he could scarcely believe so many years had passed over him. Mr. Spiller was an earnestly religious man, and the manuscripts he leaves bear testimony how far above the fleeting concerns of time he esteemed all that relates to God and eternity. His death, which took place on the 29th of May, 1873, from the breaking of a blood-vessel, was for him but the natural ending of a blameless, well-spent life. He lies buried in the little churchyard at Salcombe Regis.

Mr. Spiller's skill and ingenuity as an engineer were very great; but he was wanting in commercial capacity, nor had he the desire for riches, and hence he did not acquire a large fortune, which otherwise he might have done. He was one of those modest, unpretentious men whose existence tends to strengthen the national life and to command general respect.

Mr. FREDERICK AYRTON, the eldest son of Mr. Frederick Ayrton, a solicitor of Gray's Inn, was born in London on the 20th of March, 1812. After being educated at Ealing school, he was entered at Addiscombe in 1826 as a cadet for the East India Company's army. He passed that seminary for the Artillery, and in June 1828 was appointed a 2nd Lieutenant of the Bombay Artillery.

He returned to England in 1832, in consequence of ill health, when he seized the opportunity of studying, under the late Mr. Brunton, civil engineering. The late Mr. Robert Stephenson, having become acquainted with him, wished him to retire from the army, and become an Assistant Engineer on the London and Birmingham railway, then in course of construction, but he preferred the army.

On returning to India, at the end of 1835, he was employed in superintending experiments for boring for water in the island of Colaba, which however did not prove successful. He was next engaged on survey duties in the Deccan. He was promoted to the

rank of Lieutenant in 1837, and after acting for a short time as Quartermaster of the 1st Battalion of Artillery, he proceeded, in July 1839, to Aden, to conduct the duties of Adjutant to the European and native details of artillery there stationed.

In consequence of the views expressed by him respecting the fortifications of Aden, he was, in June 1840, appointed to act as Executive Engineer; there, whilst in command of the troops stationed at the wall which protects the British territory against incursions from the Arabs, he repulsed the last attack made by them in force to drive the British out of Aden. In 1841 he was again compelled to return to Europe from ill health. He became a Captain in June, 1843, but finding that his imperfect eyesight, which had been injured, disabled him from discharging the active duties of his military career, he was permitted to retire from the service on a pension in 1843.

He then entered himself at the Middle Temple, and in 1846 was called to the Bar; but, having taken to the study of Arabic whilst at Aden, he devoted himself to that and other literary pursuits until 1851, when Abbas Pasha, the Viceroy of Egypt, hearing of his qualifications for the office of Secretary to the Viceroy, offered him that appointment. On his arrival in Egypt, towards the end of 1851, he entered upon the duties of his office. He was much esteemed and respected by the Viceroy, who eventually, amongst other duties, confided to him the superintendence of the education of his only son, Ilhami Pasha.

He was also intrusted with the legal defence of the interests of the Egyptian Government in regard to claims brought against it by Europeans of high standing in the country, and his upright conduct in these important matters gave much satisfaction to the Viceroy, who openly expressed his sentiments regarding him. The Viceroy likewise took advantage of Mr. Ayrton's knowledge of artillery affairs to consult him frequently about a new organisation of this arm of the Egyptian army. At the death of Abbas Pasha, in 1854, Mr. Ayrton continued to assist the young Prince, his scholar, with his advice, which was much needed, and faithfully remained attached to the Prince's interests until his career prematurely ended by death at Constantinople in 1861.

From this time Mr. Ayrton's connection with the Egyptian Government ceased. He then occupied himself occasionally as a Consulting Barrister, in preparing cases for trial in the Consular Courts, but never pleaded in any of these courts. Much of his leisure was also taken up with researches into the history of

mediæval Egypt, and it is to be regretted that the results of his studies have not been given to the public. He took a great interest in the railway system of Egypt, which was commenced on his arrival in Egypt, and published a pamphlet in which he made known his views and opinions. These, however, were not properly appreciated by the Government.

The Suez Canal, during its construction, came in, as a matter of course, for a full share of his attention. He made himself perfect master of all details connected with its works, and repeatedly visited the whole undertaking from end to end.

When claims were brought against the Government of Turkey by British subjects and protégés, in consequence of the massacre of Christians at Jedda, in June, 1858, Mr. Ayrton was selected by the body of claimants to forward their views and advocate their interests. He proceeded in consequence to Jedda, to meet the English and French Commissioners (Messrs. Walne and Sabatier), who had been named by their respective Governments, in conjunction with a high Turkish functionary, to adjudicate upon the several claims preferred of indemnification for losses of property suffered during the period of outrage and massacre. Mr. Ayrton conducted his cases with much talent and perseverance, and it may be safely affirmed that the results obtained by him, in every instance, gave unbounded satisfaction to his employers, who recompensed him handsomely for his arduous exertions. But Mr. Ayrton did not remain satisfied with simply obtaining decisions from the Commissioners at Jedda. Armed with these, he proceeded to Constantinople, where he agitated in high quarters until he obtained from the Turkish Government payment of the last farthing to which his clients were entitled. To those acquainted with the dilatory mode of conducting financial matters in the East, the difficulties encountered by Mr. Ayrton, in this part of his duties, will be duly appreciated.

During the absence, on leave, of Her Majesty's representative from Cairo, Mr. Ayrton was twice intrusted with the management of all consular affairs, administrative and judicial—namely, from the 25th of April to the 9th of October, 1859, and from the 8th of June to the 17th of September, 1864.

He retired from Egypt in ill health, in 1872; but failing to obtain relief from the waters of Vichy and other places, he returned to England in 1873, and died on the 20th of June, a few days after his arrival.

Mr. Ayrton was elected an Associate of the Institution on the 9th of June, 1835.

Mr. CHARLES LOUIS AIMÉ DE BERGUE, born at Kensington on the 24th of September, 1807, was the eldest son of seventeen children of Mr. de Bergue by his wife, daughter of Mr. Rain, native of Ireland. At the age of twelve he accompanied to Paris his godfather Prince Louis de Broglio, who had, with the Prince de Polinec and several other French noblemen, commenced engineering works in the Place de la Bastille. Here he had the opportunity of exercising his natural taste for that profession, and, though almost a child, took an active part in making some valuable improvements in machinery. He was afterwards for a time with Mr. J. Waddington, an English Engineer, at St. Renie. After the Revolution of 1830 the establishment in Paris broke up. The Prince de Broglio and the Prince de Polinec came to England, and Mr. Charles de Bergue went for three years to Spain. He returned to settle in England in 1834, taking the contract for the gates of the Seraglio at Constantinople. In 1850 he built engineering works at Manchester, and engaged to construct the railway from Barcelona to Tarragona, for which he invented a new iron permanent way, that was afterwards laid down on several other lines in Spain, and was found to make a great reduction in the cost of maintenance, especially in hot climates. He also invented a useful carriage for laying the same with perfect exactitude. In 1861 he built works at Cardiff, entering extensively into bridge-building. In 1871 he took the contract for the erection of the Tay Bridge, on the plans of the Engineer of the North British railway. After completing the calculations for that work, which greatly fatigued his brain, he was seized with congestion, softening of the brain supervening, which ended his life on the 10th of April, 1873, having lost the power of speech for above twelve months. He was the inventor of many valuable tools, now in use, for shearing, punching, riveting, rail-levelling, and rivet-making. He was also the inventor of a new system of tramway, which has been laid down in Java, Syria, and other places; likewise of a new construction of lattice bridge, uniting lightness with great strength, upon which system the new Wandsworth Bridge has been built.

Mr. de Bergue was elected an Associate of the Institution of Civil Engineers on the 6th of March, 1849, and occasionally took part in its proceedings.

Mr. JOHN EVANS was born at Cawsherton, near Pembroke, on the 3rd of October, 1818, and was sent, when he was six years old, to Lady Cawdor's school, where he remained three years and gained the

second prize against one hundred and twenty boys. He next went to school at Pembroke till he was fourteen, and, after a short interval, during which he was engaged at some flour-mills, was apprenticed as a mason to his uncle Thomas, who was employed on the London and Birmingham (now London and North-Western) railway, near Denbigh Hall, and worked on that line, and on the Great Eastern (then Eastern Counties) railway, till the end of his apprenticeship. He was afterwards occupied as a mason at the Royal Exchange, at the Houses of Parliament, and at Box Tunnel on the Great Western railway. In 1844 he joined his father, who was at that time a sub-contractor on the Eastern Union railway at Manningtree, under Mr. A. Ogilvie, Assoc. Inst. C.E. While serving his apprenticeship Mr. Evans had gained some knowledge of engineering, and this probably influenced his future career, inducing him to abandon his first calling and definitively connect himself with the profession under the auspices of Mr. Ogilvie, with whom he remained until his death, engaged principally as agent on the large railway contracts carried out by that gentleman in association with the late Mr. Brassey, Assoc. Inst. C.E. In this capacity Mr. Evans was employed in many parts of the kingdom. Beginning with 1846, when he was sub-agent on the line from Ipswich to Colchester and from Ipswich to Bury St. Edmunds, he successively had charge of contracts on the Richmond and Windsor main and loop lines, with several bridges over the Thames; the North and South-Western Junction; part of the North Devon between Crediton and Barnstaple; the direct line from Godalming to Portsmouth; Stokes Bay railway and pier; the Ringwood and Christchurch; the West London Extension and branches, including a large bridge over the Thames at Battersea, and the Kingston and Twickenham with a bridge over the Thames at Kingston. The foregoing were lines either forming part of the South-Western system, or promoted by that company. He afterwards, in 1863, took charge as agent of the short line between Aston and Ditton, which included the fine bridge over the Mersey at Runcorn Gap, and materially shortened the London and North-Western route from London to Liverpool. On the completion of these important works, in 1870, Mr. Evans took charge of the construction of the new line from Kensington to Richmond, including a bridge over the Thames at Kew, and was, with the exception of a short interval, engaged on these works when his death, in his fifty-fifth year, took place on the 14th of December, 1872. Mr. Evans joined the Institution of Civil Engineers as an Associate on the 9th of January, 1866.

Mr. CHARLES LARKIN FRANCIS was born in South Lambeth on the 10th of December, 1801, and was the eldest son of Mr. Charles Francis, of Belgrave House, Vauxhall, a Justice of the Peace for the county of Surrey.

To within a short period of his death he was the head of the firm of Charles Francis and Sons, cement manufacturers, of London and the Isle of Wight, whose business transactions extended to all parts of the world, by far the largest part of the trade coming from foreign countries. The extensive fortifications and harbours of Odessa, Trieste, Cherbourg, and the Brazils owe a large portion of their strength and solidity to the cement exported by this firm. In the Great Exhibition of 1851 he exhibited an expeditious and cheap mode of erecting dwellings for the poor—at once dry, healthy, and more durable than brick—made of concrete, viz., cement and shingle, and received a medal and other acknowledgments.

In early life he travelled a good deal abroad, and resided in different parts of Italy and Germany. At one time he was a marble merchant, and visited Carrara to inspect the marble quarries, for which purpose he had letters of introduction from Chantrey to Canova. He was exceedingly fond of literary and scientific studies, particularly engineering and geology, and for four or five years he gratuitously wrote the leading article in the "Wilts and Gloucester Standard."

He was the originator of the City Steamboat Company, of which he was chairman for many years, and repeatedly received handsome testimonials from the Company for his great labours in its behalf. Ever ready to help those who required advice and assistance, he was beloved by all who had the happiness of his acquaintance.

Mr. Francis was elected an Associate of the Institution on the 6th of February, 1838. He died at his residence in Gloucester Street, S.W., on the 3rd of February, 1873, aged seventy-one years, and was buried in Norwood Cemetery.

Mr. THOMAS GREENWOOD[1] was born at Gildersome, near Leeds. After serving some years in his father's machine shop, he, about the year 1833, established himself, in conjunction with his brother, as a machine and tool maker. On the death

[1] A detailed memoir of Mr. Greenwood, from which this notice has been mainly compiled, was inserted in the "Leeds Times," February 17, 1873.

of his brother, he, after a short engagement with Messrs. Whitham, of the Perseverance Ironworks, entered the drawing office of Sir Peter Fairbairn, of the Wellington Foundry, Leeds, and continued with him as manager, and shortly afterwards as partner along with Mr. Batley, under the firm of Fairbairn, Greenwood, and Batley, until 1856. Sir Peter Fairbairn principally devoted himself to the manufacture of flax machinery; but the outbreak of the Russian war so interfered with the ordinary business of the firm that nearly every order on hand was countermanded, and it became a question how to utilise the existing machinery and keep the men fully employed. At this crisis Mr. Greenwood's energetic mind conceived the idea of constructing machinery for the manufacture of the Enfield rifle and other war stores. Having persuaded Sir Peter Fairbairn to take up this new branch of art, he successfully competed with the most celebrated and experienced American tool-makers (who at that time had entire charge of the Enfield factories) in making machinery for the manufacture of interchangeable small arms for the British Government, and was thus instrumental in securing for this country a new branch of machine making. On the close of the Russian war in 1856, Mr. Greenwood left the Wellington Foundry, and, associating himself with Mr. Batley, who had been formerly cashier in the same works, established the Albion Foundry, under the style of Greenwood and Batley. Subsequently this firm built a large and extensive range of premises in Armley Road; and by way of preserving the old association, they called their new premises the Albion Works, at the same time keeping up their humbler establishment at East Street. Here the firm rapidly gained a high position, and it is not too much to say that the Albion Works, Leeds, are known all over the civilised world. Following the example of Sir Peter Fairbairn, Mr. Greenwood's attention was principally devoted to the production of flax and silk spinning, and small-arm machinery, thus curiously lending himself to the development of arts diametrically opposed to each other. Mr. Greenwood, in 1871, went to Russia to establish a small-arm manufactory in that empire, and there obtained one of the largest orders his firm ever received. He also went to America, and while there in the summer of 1872, suffered severely from the effects of the intense heat which then prevailed, and to which suffering his death, a few months after, may be traced.

Mr. Greenwood's life was a story of self-help and enterprise, and the success he ultimately achieved was as much owing to his industry and perseverance as to his undoubtedly high me-

chanical talents. On the subjects with which he was more particularly acquainted, Mr. Greenwood contributed Papers which have been published in the Proceedings of the Institution of Mechanical Engineers, of which society he was a Member.[1] As a citizen of Leeds he was held in deserved respect. He at one time was a member of the Town Council, and also acted as Chairman of the Leeds Board of overseers. The news of his death, which occurred on the 9th of February, 1873, at Gipsy Hill, near the Crystal Palace, caused general regret; and his funeral, at the Woodhouse Cemetery, whither his remains had been conveyed from London, partook of the nature of a public ceremony, sixteen hundred of the workpeople employed by the firm following him to the grave. Mr. Greenwood was elected an Associate of the Institution of Civil Engineers on the 4th of February, 1860.

Mr. THOMAS CRUMP HAMBLING was born at East Dereham, Norfolk, on the 25th of September, 1835. After serving an apprenticeship to Messrs. Ransome and Sims, at Ipswich, he was for three years in the establishment of Messrs. Maudslay, Sons, and Field, which he left to become assistant manager at Messrs. Porter and Co.'s works, Tividale. He was then engaged by the Spanish Government to carry out public works, principally the erection of lighthouses on the coast. These he superintended under difficult and sometimes dangerous circumstances, and on their completion—after a short engagement under Mr. Robert C. May, M. Inst. C.E., —he set up on his own account in London as a Consulting Engineer. He had laid the foundation of a successful practice, when his career was cut short by accidentally taking an overdose of laudanum, from the effects of which he died on the 14th of March, 1873, in his thirty-eighth year.

Mr. Hambling was elected as Associate of the Institution on the 6th of April, 1869, and frequently attended the meetings.

Mr. HAMILTON EDWARD HARWOOD, son of Mr. William Harwood, of London, was articled, about 1840, to Mr. Francis Thompson, the well-known architect. He assisted Mr. Thompson, who placed great confidence in his business qualifications, on the stations of the North Midland, South Eastern, and Chester and Holyhead railways, also on the masonry of the Britannia Bridge,

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[1] *Vide* Minutes of Proceedings Inst. M.E., 1862, p. 328; 1865, p. 103; and 1868, p. 105.

Tweed Viaduct, and High Level Bridge at Newcastle, and other large structures. On leaving that office in 1850, he entered the service of the late Mr. Charles Heard Wild, under whom he was successively engaged on the masonry of various engineering works, upon the Great Exhibition building in Hyde Park, and on the Crystal Palace works at Sydenham. In the year 1855 he was appointed Surveyor to the Board of Admiralty for the Naval Yard at Keyham, and in the following year his appointment was extended to all the principal naval establishments at home. In October 1863 he was specially selected by the Board to visit Malta, with a view to the settlement of the contractors' claims for works on the great harbour at that station. He likewise carried on private practice as an architect and surveyor, in the course of which he designed and erected several town and country residences of magnitude, and was also professionally engaged by many of the leading Engineers in connection with railway-station works, for which his extensive knowledge of constructive detail and arrangement peculiarly fitted him.

Mr. Harwood was highly esteemed by his professional brethren for his thorough integrity, as well as for the extreme care and zeal with which he performed his duties, and his moral worth and sterling qualities had endeared him to all his private friends. He was elected an Associate of the Institution of Civil Engineers on the 16th of March, 1866, and he died after a short illness at his residence, Carlyle Square, Chelsea, on the 31st of December, 1872, in the forty-ninth year of his age.

Mr. GEORGE WILLIAM HORN was born in London in the year 1801. After for some years discharging, as deputy, the duties of Clerk of the Declaration in the then Court of King's Bench, the late Lord Ellenborough appointed him to that office, which he held until its abolition early in the present reign.

In 1839 Mr. Horn joined the London and South-Western Railway Company, as head of the Audit department. During the next fifteen years, in addition to the routine duties of the office, he was much engaged in preparing elaborate statements, to be used in appeals against the rating assessments on various parts of the line; and, after resigning this post in 1853, he continued to advise the company in these cases. From that date he was occupied for many years in promoting narrow-gauge railways to the West of England in connection with the South-Western system, and was secretary of several lines subsequently amalgamated with it; among others, the Portsmouth direct and the Devon and Cornwall.

By means of this last a narrow-gauge communication was effected between London, Plymouth, and Devonport. Mr. Horn was also secretary of the Rhymney Railway Company from its incorporation to the opening of the line, four years later, when the offices were removed to Cardiff; and was actively interested in several metropolitan schemes for connecting some of the great trunk lines in the outskirts of London. He was elected an Associate of the Institution of Civil Engineers on the 5th of December, 1865. Earlier in life he was for a time a Member of the Royal Archæological Institute of Great Britain and Ireland. In 1868, shortly after the murder of his only son near Rosario, in the Argentine Republic, Mr. Horn relinquished all his appointments except two auditorships. Energy and interest in life returned in time, and he spent his remaining years chiefly in travelling. After a short illness, he died at Interlaken on the 9th of July, 1873, in his seventy-second year.

Throughout life Mr. Horn took a keen interest in social and political questions, regarding them from the point of view of the Philosophical Radicals. His character was singularly well-balanced and harmonious. He was unsparing of trouble, and put his whole strength into all he undertook. Upright and honourable, affectionate, generous and genial, with no littleness nor pretence in his nature, he was warmly loved by his friends and always a favourite with the young. Preserving to the last an energetic freshness of heart, and a memory wont to revert to the brighter side of things, he said, two days before death, "I have had a long life, and have enjoyed it to the end."

Mr. JOHN LAWSON was born at Skerton, near Lancaster, on the 25th of May, 1824, and was educated at the national school in that town. At the age of fourteen he entered, as a pupil, the office of the late Mr. William Lamb, of Hay Carr, near Lancaster, who was then agent for the extensive estates of the Duke of Hamilton in the County Palatine. Mr. Lamb, though nominally a land agent, had been brought up under the late Mr. Miller, of Preston, who called himself a surveyor, as was customary in those days, but who was really engaged in all the engineering works of the district, such as the laying out and making of roads and canals, the reclamation of land, main drainage operations, &c. Mr. Lawson spent nearly seven years at Hay Carr, during which time he was engaged in surveying and preparing plans of several townships for tithe-commutation purposes; in laying out roads, watercourses and extensive drainage works; in the valuation of land

for railways and buildings, and in settling accommodation works for landowners, in connection with the railways—the Lancaster and Preston and Lancaster and Carlisle—then in course of construction in the neighbourhood.

He also had to undertake the preparation of plans for new farm buildings, and to superintend their erection, and other works of improvement in roads, fences, drains, &c., on large estates under the management of a progressive, educated, and thoroughly competent agent. For the last two years of his pupilage, Mr. Lawson was responsible for the management of the office and the general direction of the whole staff. Mr. Lamb was a person of precise and rigorous habits, who required that his work should be done with the utmost regularity and accuracy, and the result of this seven years' training on a man of Mr. Lawson's acuteness and industry was evinced in the clear, systematic, and painstaking intelligence which he subsequently brought to bear upon all that he undertook. After leaving Hay Carr in the year 1845, he was appointed the Resident Engineer and agent for the Bold Hall, Burtonwood, and Sutton estates in the neighbourhood of Warrington, then belonging to Sir Henry Bold Houghton, Bart., and he held this appointment for about three years. During this period he laid out and executed extensive improvements in the roads, drives, watercourses and drainage of the estates, and erected some of the most extensive farm buildings in the north of England. In 1848, in conjunction with Mr. Hugh U. M'Kie, Assoc. Inst. C.E., he purchased the business of Mr. John Watson, M. Inst. C.E., and carried that business on in Lancaster until the year 1856, during which time he was actively occupied in railway and estate surveys, in road making, bridge building, harbour works, laying out building land, &c., and all the varied practice of a country engineer's office. In 1850 he commenced the preliminary investigations, gaugings, surveys, &c., in connection with the Lancaster water supply, and subsequently got up the parliamentary plans for these works. After the passing of the Act he was engaged by Mr. Rawlinson, C.B., M. Inst. C.E., and under him he carried out, as Resident, the whole of the works of water supply and sewerage of the town.

In 1856 he left Lancaster and entered Mr. Rawlinson's office in London, as principal assistant and manager, and was thus for several years intimately connected with the various works of town improvement that Mr. Rawlinson was then engaged upon. In 1862, on Mr. Rawlinson's retirement from active private practice, Mr. Lawson took over the business, and carried it on up to the

time of his death; for the later years of his life in partnership with Mr. James Mansergh, M. Inst. C.E.

Having devoted his attention principally to sanitary engineering, Mr. Lawson was extensively employed in reporting upon and constructing works for the supply of water to towns, and for the removal and treatment of sewage. Among others may be enumerated Bedford, Cockermouth, Workington, Maryport, Grantham, Horncastle, Tunbridge Wells, Hexham, Keswick, Rotherham, Reading, Lincoln, Middlesborough, Barnet, Burton-on-Trent, Clevedon, Sherborne, &c. In 1867 Mr. Lawson was sent out, by the Colonial Office, to report upon the sanitary condition of Valetta and the other towns adjoining in the island of Malta, and to prepare a scheme for the sewering of those places. In later years he was consulted as to the disposal of the sewage of many towns, such as Birmingham, Darlington, Windsor, Twickenham, Southport, &c., and was Consulting Engineer for two of the earliest Bills—viz., Blackburn and Reading—that were brought into Parliament for the purpose of obtaining compulsory powers for the purchase of land for sewage purification purposes. For some time prior to his death Mr. Lawson's health gradually broke down, as a consequence, it is believed, of overwork and the anxieties specially incident to his occupation, and he died on the 7th of February, 1873, at the comparatively early age of forty-eight.

Mr. Lawson had a remarkable faculty for unravelling the mysteries of masses of figures, and so marshalling them in a tabular form as to make them self-explanatory. He was a self-possessed and trustworthy witness on public inquiries and before Parliamentary Committees, where his honest, serious style of giving evidence was effective and convincing. He was a man of modest and unobtrusive habits, and attained his position by dint of sterling merit. He was highly esteemed by all with whom he was brought into contact on business matters, for his quiet, earnest thoughtfulness, and his conscientious devotion to his clients' interests. Possessing a clear head and sound judgment, he was looked up to by his friends as a safe and reliable counsellor, and his unselfish kindliness of heart never permitted him to spare himself labour or trouble which would benefit them.

Mr. Lawson was elected an Associate of the Institution on the 1st of March, 1859.

Mr. JAMES GARTH MARSHALL was born at Leeds on the 20th of February, 1802. He was the third son of the late Mr. John Marshall, of Headingley, Leeds, sometime M.P. for Yorkshire,

who acquired great wealth towards the close of the last and the beginning of the present century by the successful introduction of a variety of mechanical improvements in flax-spinning. On attaining manhood he left Edinburgh, where he had shared the singular educational advantages which at that time drew so many distinguished men to cultivate thought, science, and literature under the eminent professors of the Scotch University, and joined his father and brother as a member of the widely-known firm, of Marshall and Co., flax-spinners, of Leeds and Shrewsbury. On the death of his father he became more prominently identified with the interests of his native place. He was amongst the earliest advocates of popular, and ultimately of state, education, and showed the value which he put upon the instruction of the young by erecting, along with the other members of his firm, schools at Holbeck, intended for the multitudes of children connected with the firm's extensive mills. These schools soon assumed the character, which they have to this day maintained, of model schools for the neighbourhood. Among other striking proofs of his regard for the highest interests of those who came under his care was the building and endowment of the church of St. John the Evangelist, Holbeck, which was erected in 1849 from the designs of Sir Gilbert Scott, and is a fine specimen of the Early English style. At the general election of 1847 the Liberal party was rent asunder by differences of opinion on the subject of voluntary, as opposed to state education, and Mr. James Garth Marshall, being a strong advocate for the latter system, was induced to stand as its champion. In the result he was elected one of the members for Leeds, and he faithfully represented the borough until the dissolution of 1852. From the latter date he became less prominent as a public man, his health having materially suffered, but his interest in public questions remained unchanged, and he nominated his successor in the representation, the Rt. Hon. M. Talbot Baines. He supported the candidature of Lord Amberley in 1865.

Mr. Marshall's political opinions were those of a very decided Liberal. He was from the first an advocate of the Ballot, and when the Reform question was again agitated he published a pamphlet in favour of a scheme resembling the philosophic plan of popular representation with which Mr. Hare's name has been associated. Mr. Marshall's own suggestion for the just representation of minorities was what he named the "Cumulative Vote." But the kindly sympathies of Mr. Marshall prompted him to even more congenial work in the promotion and manage-

ment of various philanthropic institutions. The Leeds Social Improvement Society, founded for the relief of deserving cases of distress and the repression of mendicity, owes its existence chiefly to Mr. Marshall, whose successive appeals led to the realisation in Leeds of the results which have proved so great a blessing in Edinburgh and elsewhere. He took an active interest in the Leeds Philosophical Society, and for many years acted as one of its honorary curators. His scientific knowledge, which was considerable, found ample scope in literary contributions on geology, and other branches of science, and in connection with his prosperous business. Unfortunately there are no records of the improvements made by Mr. Marshall in flax-spinning, as during all the earlier part of his life he never took out any patents, and his inventions have long been in such general use that their interest has died out. The great success which eventually crowned the enterprise and perseverance of Mr. Marshall's father, the late Mr. John Marshall, are so well known as to need no comment. It may however be of interest to state that the following description, taken from Mr. Disraeli's "Sybil," is well understood to apply to Marshall's extensive flax mills at Holbeck:—"On the banks of his native stream he had built a factory, which was now one of the marvels of the district—one might almost say of the country—a single room spreading over nearly two acres, and holding more than 2,000 workpeople. The roof of groined arches, lighted by ventilating domes at the height of 18 feet, was supported by hollow cast-iron columns, through which the drainage of the roof was effected. The height of the ordinary rooms in which the workpeople in manufactories are engaged is not more than from nine to eleven feet, and these are built in stories, and the heat and effluvia of the lower rooms communicated to those above, and the difficulty of ventilation insurmountable. At Mr. Trafford's, however, by an ingenious process not unlike that which is practised in the House of Commons, the ventilation was also carried on from below, so that the whole building was kept at a steady temperature, and little susceptible to atmospheric influence. The physical advantages of thus carrying on the whole work in one chamber are great; in the improved health of the people, the security against dangerous accidents for women and youth, and the reduced fatigue resulting from not having to ascend and descend and carry materials to the higher rooms. But the moral advantages resulting from superior inspection and general observation are not less important; the child works under the eye of the parent, the parent under that of the superior workman; the inspector or employer at a glance can

behold all. When the workpeople of Mr. Trafford left his factory they were not forgotten. Deeply had he pondered on the influence of the employer on the health and content of his workpeople. He knew well that the domestic virtues are dependent on the existence of a home."

Being by nature extremely shy, a strong sense of duty alone seemed to force Mr. Marshall into publicity. Although not fluent as an orator, he was always listened to with marked respect when he spoke in public, his opinions being based upon solid information and independent thought. Like his father, he had no passion for honour or popularity, yet earned a gratifying measure of both by virtue of inflexible honesty of character, wise generosity of disposition, and sterling abilities. It may be said with all truth that, in Leeds especially, the loss of so estimable a citizen will be long felt. William Wordsworth, Dr. Arnold, Professor Sedgwick, were his earliest, fast friends.

Mr. Marshall was elected an Associate of the Institution of Civil Engineers on the 1st of May, 1838, and although his residence in the country prevented his attendance at the meetings, he took a great interest in its welfare.[1]

Mr. FREDERIC MOLESWORTH PFEIL was born in the year 1835, and began his professional life at an early age, serving a regular pupilage from 1849 to 1852 under Mr. W. Colman, after which he was engaged for six years in various departments of engineering, amongst others, in the offices of Messrs. Porks and Co., mechanical engineers; in Woolwich Arsenal, on Government works of importance under Colonel Beatson, R.E., and Mr. D. Murray, C.E.; and a similar appointment at Aldershot under Colonel Collinson, R.E. He was also for short periods employed under Colonel Dawson, R.E., Tithe Commissioner; Messrs. Locke and Errington, MM. Inst. C.E., and in the office of the Director of Works of the Admiralty, under the late Mr. William Scamp, M. Inst. C.E. He proceeded to the Cape of Good Hope about the year 1858, and was employed for nearly two years in the Colonial Engineer's Department, Cape Colony, and afterwards for a like period as Engineer to the Mossel Bay Harbour Board, in charge of the construction of a landing pier and lighthouse on Cape St. Blaize. He then established himself in general practice

[1] The facts contained in the foregoing memoir are mainly extracted from a memoir which appeared in the "Leeds Mercury" of Oct. 24, 1873.—Ed.

as a Civil Engineer at Port Elizabeth, and during that time designed and executed several public and private buildings, and other works; he also held the office of Engineer to the Commissioners for Improving the Port and Harbour of Algoa Bay, and acted as Inspecting and Superintending Engineer for Roads, Bridges, Lighthouses, &c., under the Public Works Department of the Cape. On the occurrence of the commercial collapse at the Cape in 1869, Mr. Pfeil returned to England for a short time, and then accepted the position of Divisional Resident Engineer on the Madras railway, which he held for little more than three years, when his death occurred on the 20th of October, 1873, at the comparatively early age of thirty-eight years. He joined the Institution as an Associate on the 6th of February, 1872.

Alderman Sir DAVID SALOMONS, Bart., M.P., descended from a family of Jewish merchants long resident in London, was born on the 22nd of November, 1797. He was the second son of the late Mr. Levy Salomons, an underwriter of Lloyd's. On starting in life his chief ambition was to remove all disabilities attaching to the Jews, and to advocate religious equality generally. Inheriting the associations of his father and grandfather, David Salomons chose at first to enter on the path which led to municipal honours; but in those days the Jews were not allowed to exercise municipal or parliamentary rights, and a long and arduous struggle was in store for him before he could gratify his ambition. He connected himself with a band of men whose education and spirit placed them in a high position amongst the Jewish community of that epoch, and whose whole aim in life was the prosecution of the rights of Jewish Englishmen. Among them the names of Isaac Lyon Goldsmid, Barnard Van Oven, S. J. Waley, and Louis Lucas were prominent. In 1835 Mr. Salomons boldly attempted admission into the municipality of London. His popularity, ability, and courage succeeded, and he became the first Jewish Sheriff of London and Middlesex. A few years later he was appointed High Sheriff of Kent, in which county his estates were situate. Here again he was the first Jewish high sheriff in the country. In 1835 he was elected Alderman for the ward of Dowgate; but in this case he received a check, not being permitted to take his seat in Guildhall. Nothing daunted, he in 1844 again became candidate for a vacant aldermanic gown, and the electors of Portsoken Ward chose him as their representative. But now, as on the previous occasion, he was obliged to resign the post which the laws of his

country did not permit him to fill though his fellow-citizens called him to it. It was not until 1847 that Mr. Salomons again offered himself for election, but in the interval Sir Robert Peel had carried a bill securing municipal privileges to his fellow-subjects, and he was returned for the ancient ward of Cordwainers, this time taking his seat in the Guildhall. In due course he became Lord Mayor of London, on which occasion "The Times" congratulated its readers that they had at last got a chief magistrate who could speak the Queen's English. The mayoralty of Alderman Salomons was a series of triumphs. His gracious demeanour and pleasant presence, his great hospitality and affable bearing, rendered his career at the Mansion House one of exceptional brilliancy and popularity. He had the honour of receiving as a civic guest King Victor Emmanuel, the ally of Great Britain in the contest raging between England, France, and Turkey, on the one side, and Russia on the other. It was also during his mayoralty that peace was proclaimed, and it was expected that he would have had a baronetcy conferred upon him. But for some unknown reason this was not done, and the omission caused some notice at the time, the more so that the Lord Mayors who had received the Sultan and the French Emperor had been made baronets. It was said that a knighthood had been offered him, but he refused it. Lord Mayor Salomons' decisions on the judicial bench gave satisfaction. He had previously, with a view perhaps to performing his duties with greater propriety, entered himself as a barrister at the Middle Temple, and was called to the bar in the year 1849.

The first step he took in parliamentary life was to refuse a seat for a borough belonging to the Lowther family, which was offered to him for a time only. He subsequently contested unsuccessfully Old Shoreham in 1837, Maidstone in 1841, and Greenwich in 1847. In 1851 he was successful at Greenwich; and it was his bold attempt to take his seat in the House of Commons which drew the attention of the whole community to the disabilities of the Jews, which had been eloquently denounced by Macaulay. At that time the oath taken by members of parliament contained the words "on the true faith of a Christian." In taking the oath Alderman Salomons followed the example of Baron Lionel de Rothschild, who was sworn on the Old Testament, omitting the words above referred to. Baron Rothschild withdrew, when requested to do so by the Speaker; but Alderman Salomons, acting under legal advice, and with the support of the leaders among his co-religionists, sat down on one of the benches on the right of the chair. He afterwards retired, but returned by arrangement on

another day, and took his seat below the gangway on the ministerial side. A hurricane of cheers and denunciations followed the entry of the member for Greenwich, and the state of the law was thereupon discussed, the supporters of Mr. Salomons proposing to admit him by resolution, without the concurrence of the House of Lords. Acting on the precedent of Pease, the Quaker, who had been excused from taking the oaths, Mr. Salomons voted upon several questions, one to the effect that he should be requested to withdraw. Mr. Salomons himself addressed the House, and his courtly and deferential manner made a most favourable impression; but the motion was carried against him. On the 21st of July, 1851, he again attempted to take his seat in the House. The Speaker requested him to withdraw. Mr. Osborne moved as an amendment that Mr. Salomons be entitled to take his seat, but on a division was defeated by 229 to 81. The Speaker then directed the sergeant-at-arms to remove Mr. Salomons, who had previously declared his readiness to leave the House provided enough were done to make it appear that he acted under coercion. The sergeant-at-arms accordingly touched him on the shoulder, and he immediately rose and retired. Subsequently the electors of Greenwich were unsuccessful in their endeavours to be heard by petition at the bar of the House, and on the 19th of April, 1852, Baron Alderson delivered judgment in the case of Miller *v.* Salomons an action involving a penalty of £500 for unlawful voting under the Acts of George I. and George III. In this decision the Lord Chief Baron and Baron Parke concurred, but Baron Martin was of opinion that the defendant had lawfully taken the oath. The seat he unlawfully sat upon in the House of Commons was bought by him when the House moved into its new buildings; and it was always pointed to by him with delight at his country house at Tunbridge Wells. After the passing of the Act for the removal of Jewish disabilities, Alderman Salomons was again elected for Greenwich, which he represented up to the day of his death. At the general election of 1868 Mr. Gladstone became his colleague, and soon after the accession to office of the right hon. gentleman as First Lord of the Treasury, Mr. Salomons was made a baronet of the United Kingdom, with special remainder to his nephew, now Sir David Lionel Salomons. Sir David was looked upon in the House as an authority on financial matters, and acted as chairman of parliamentary committees on Australian coinage, and Metropolitan bridges. In connection with the latter subject he was up to his last illness preparing to denounce the London coal dues. He took a prominent part in the management of the London and Westminster

Bank, of which great institution he was one of the founders, and was chairman up to the day of his death. He was also a trustee of the London Life Assurance Society, and regularly attended at the offices of these two large concerns to transact business on his appointed days throughout the year. In the country, he was a magistrate for Middlesex, Kent, and Sussex, and Deputy Lieutenant for Kent and Middlesex, and took a leading part on the bench. He was the author of pamphlets on "English and Foreign Railways," "Banking," "The Corn Laws," &c., which attracted considerable attention in their day. Sir David Salomons was a discerning patron of art, possessing at his seat, Broom Hill, Tunbridge Wells, a fine collection of modern paintings. He was also a member of several learned societies, and joined The Institution of Civil Engineers as an Associate on the 4th of February, 1862.

Sir David had been for a long time in precarious health, but seemed to rally, and it was hoped that he might be spared for a few years longer, though his great age scarcely justified such a hope. A relapse having occurred, he gradually sank, and breathed his last on the 18th of July, 1873. The news of his death caused sincere grief among the members of the Jewish persuasion in England. He belonged not only to his family and to his friends, but to the whole religious community of which he was a distinguished ornament, and to the country of which he was a patriotic and useful servant.

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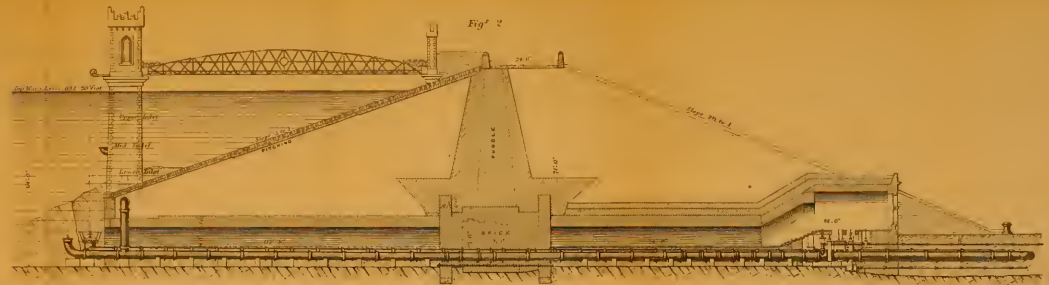
Fig. 1

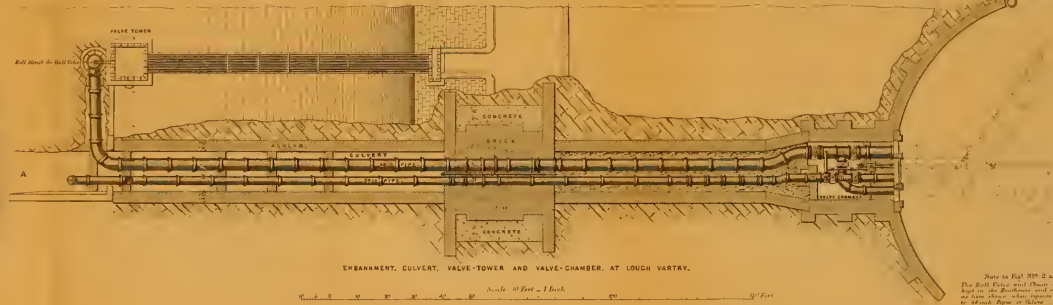
GENERAL PLAN

Scale of Miles

Fig. 2



SECTION A TO B ON PLAN.

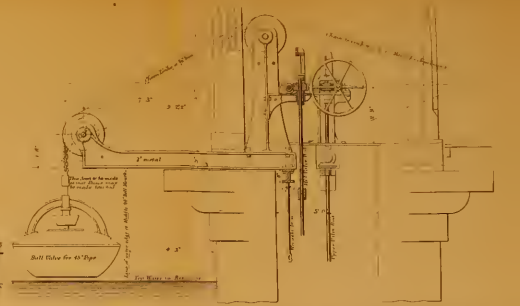


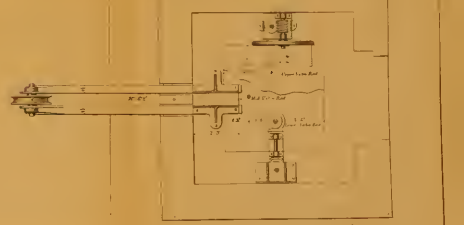
EMBANKMENT, CULVERT, VALVE-TOWER AND VALVE-CHAMBER, AT LOUGH VARTRY.

Scale 40 Feet = 1 Inch

Note to Figs. 2 and 3
The Bell Valve and Chain are always kept in the Reservoir and only applied as here shewn when repairs are required to 48 inch Pipes or Valves

Fig. 3





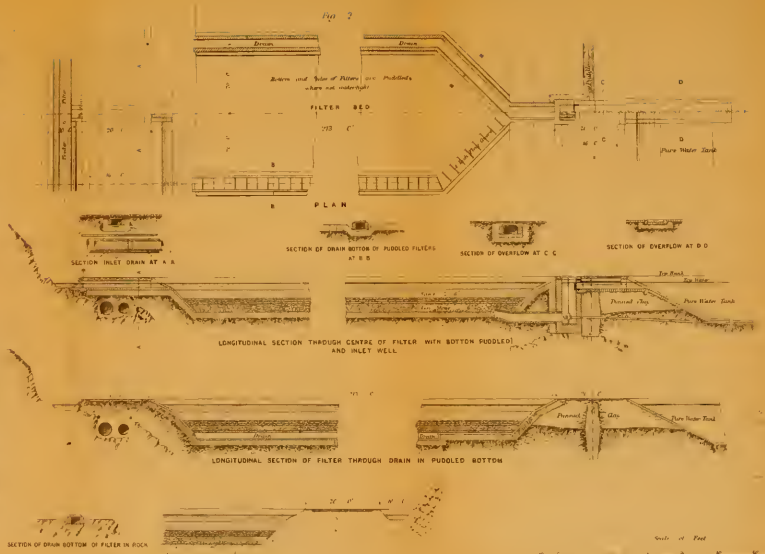
GEARING FOR BALL AND INLET VALVES.

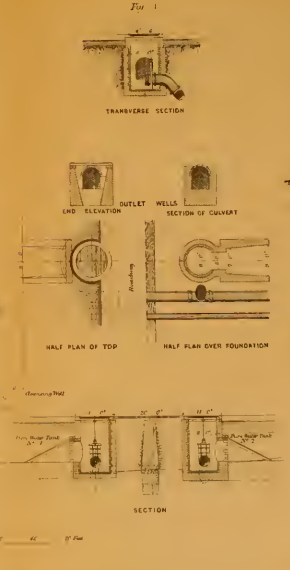
Scale of Feet

Lecturer to The Institution of Civil Engineers

DUBLIN WATER WORKS.

PLAN OF FILTER BEDS AND EMBANKMENT


Bottom and Side of Filters are Puddled where not underdrain
FILTER BED
PLAN
SECTION INLET DRAIN AT A A
SECTION OF DRAIN BOTTOM OF PUDDLED FILTERS AT B B
SECTION OF OVERFLOW AT C C
SECTION OF OVERFLOW AT D D
Pure Water Tank
LONGITUDINAL SECTION THROUGH CENTRE OF FILTER WITH BOTTOM PUDDLED AND INLET WELL
LONGITUDINAL SECTION OF FILTER THROUGH DRAIN IN PUDDLED BOTTOM
SECTION OF DRAIN BOTTOM OF FILTER IN ROCK
LONGITUDINAL SECTION OF FILTER IN ROCK



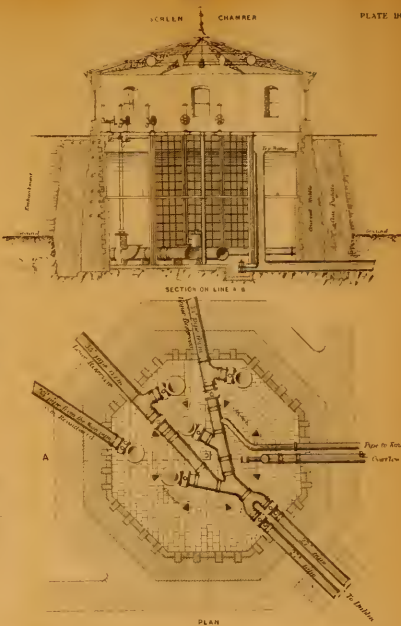
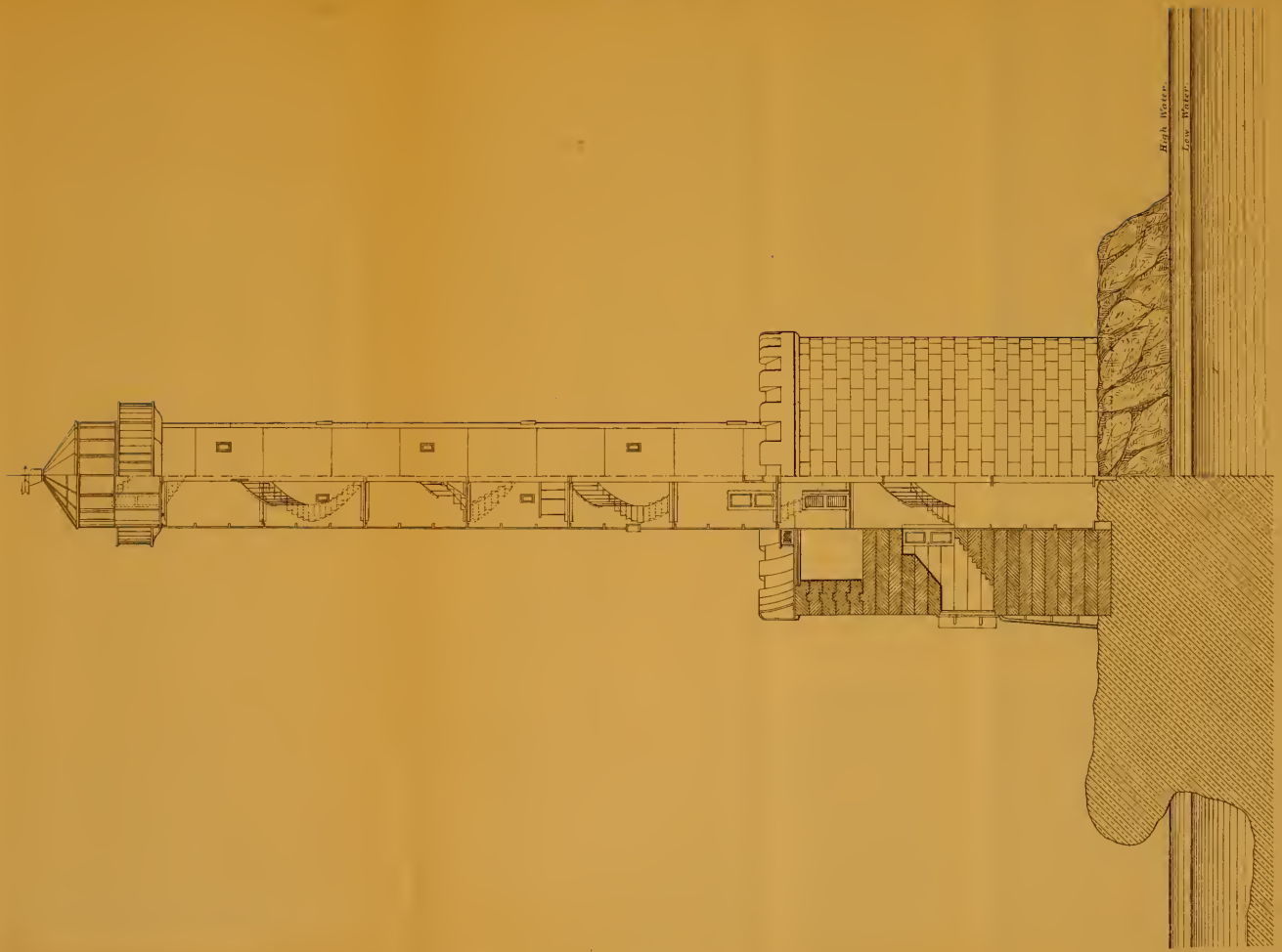


CHART SHEWING GREAT BASSES AND NEIGHBOURING LIGHTS.
Hummocks or Knuckles.
Haycock.
Rugged Ridge
Mugamie
Pagoda Peak.
Nipple Hill (903)
Chimney Hill (445)
Light Vessel.
Little Basses
Kattregamme Hill (1572)
Kirinde
POINT DE GALLE
BELLIGLA OR REDBAY.
DONDRA HEAD
LIMIT OF POINT DE GALLE LIGHT. HEIGHT 100 FEET. VIS. 15.91 MILES.
LITTLE BASSES LIGHT VESSEL. LIGHT VIS. 11 MILES.
LIMIT OF LITTLE BASSES LIGHT. 110 FEET HIGH. VIS. 19.47 MILES.
GREAT BASSES
LIMIT OF GREAT BASSES LIGHT. 110 FEET HIGH. VIS. 16.47 MILES.
80°
81°
82°



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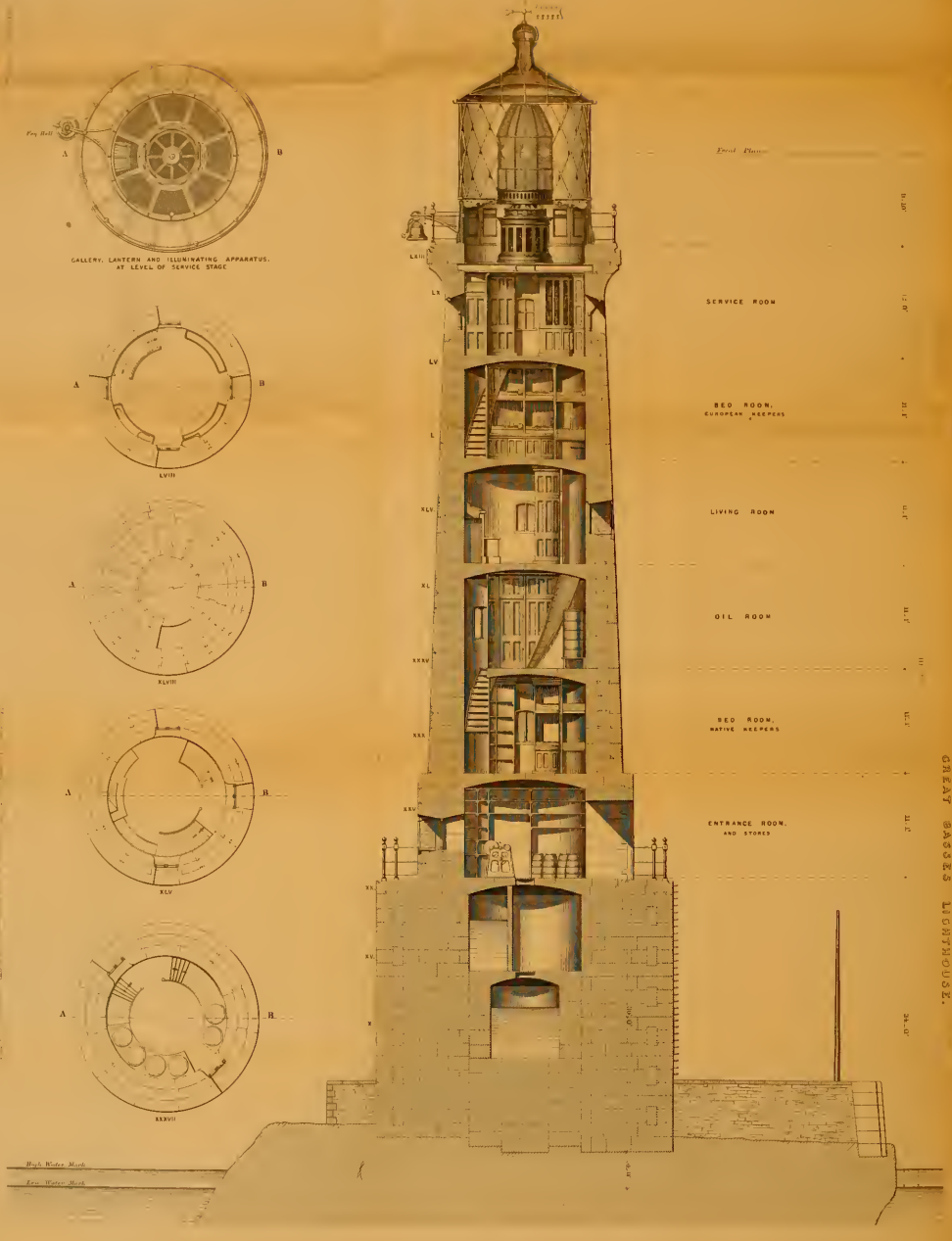
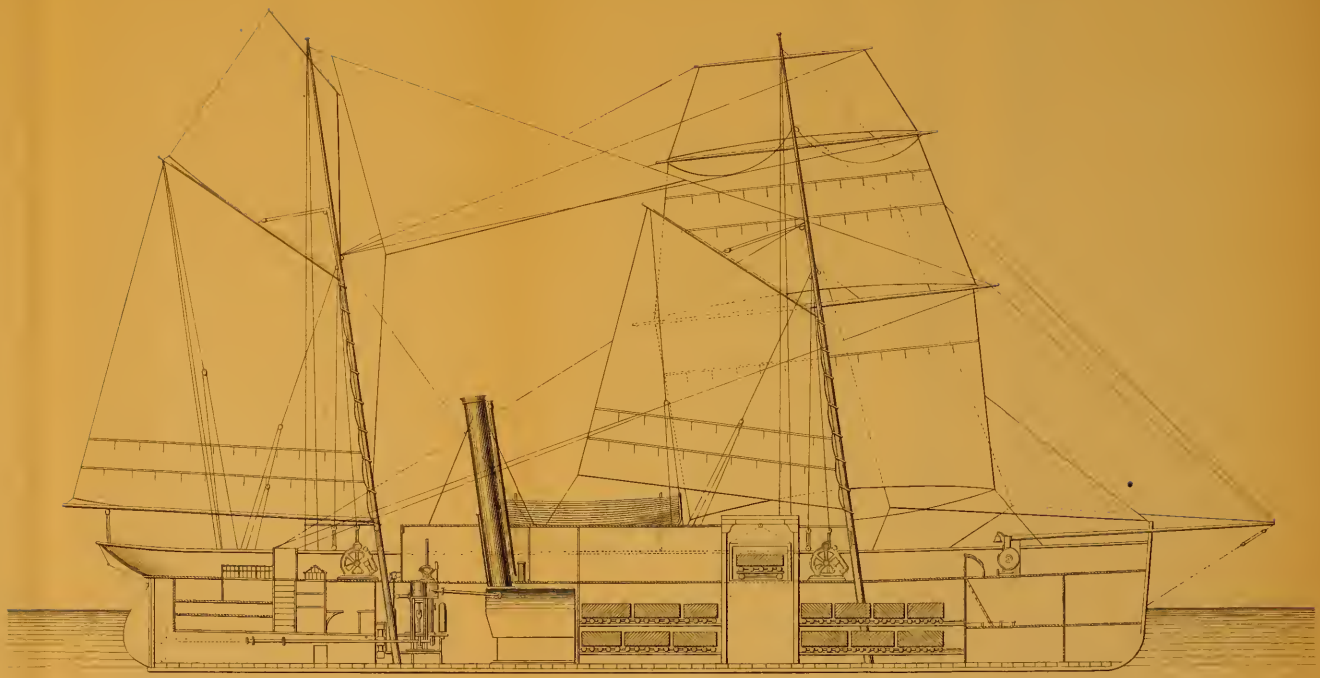
THOS KELL LITH. 40 KING ST COVENT GARDEN

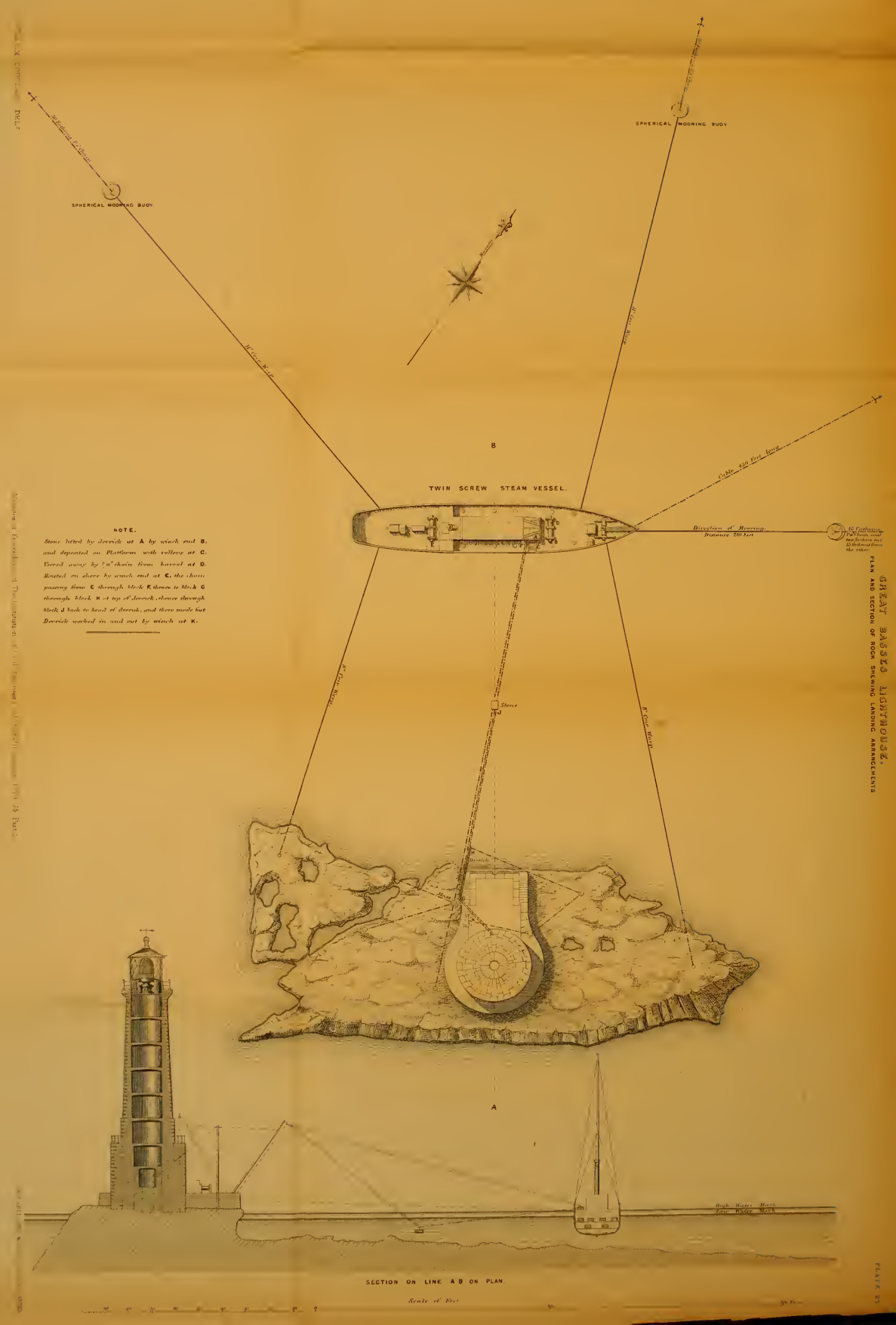

GALLERY, LANTERN AND ILLUMINATING APPARATUS, AT LEVEL OF SERVICE STAGE
SERVICE ROOM
BED ROOM, EUROPEAN KEEPERS
LIVING ROOM
OIL ROOM
BED ROOM, NATIVE KEEPERS
ENTRANCE ROOM, AND STORES
GREAT BASSAS LIGHTHOUSE.
SECTION ON LINE A B ON PLAN OF COURSES.
Scale ½ Inch = 1 Foot



SECTIONAL ELEVATION OF TWIN SCREW STEAM VESSEL.

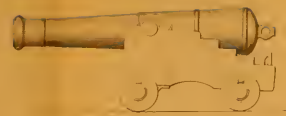
Scale of Feet.

Ins 0 5 10 15 20 25 30 35 40 45 50 75 100 Feet.


SPHERICAL MOORING BUOY
SPHERICAL MOORING BUOY
TWIN SCREW STEAM VESSEL.
B
A
Stone
NOTE.
Stone hitted by derrick at A by winch end B, and deposited on Platform with rollers at C. Vessel away by 7in chain from hawsel at D. Heated on shore by winch end at C, the chain passing from E through block F down to block G through block H at top of derrick, thence through block J back to head of derrick, and there made fast. Derrick worked in and out by winch at K.
Direction of Mooring.
Distance 200 feet
High Water Mark
Low Water Mark
SECTION ON LINE A B ON PLAN.
Scale of Feet
GREAT BASSES LIGHTHOUSE.
PLAN AND SECTION OF ROCK SHEWING LANDING ARRANGEMENTS
PLATE 27

GUN CARRIAGES

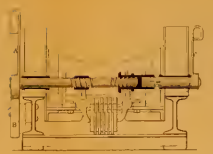
AND MECHANICAL ARRANGEMENTS FOR WORKING HEAVY ORDNANCE



COMMON SHIP CARRIAGE

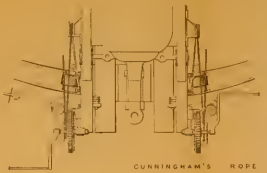
SELF ACTING COMPRESSOR FOR WOOD SLIDE

FOR IRON SLIDE

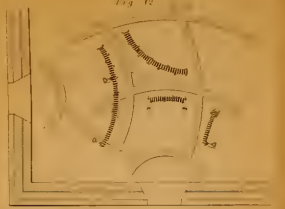


SECTION

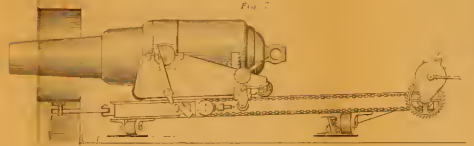
PLATE COMPRESSOR SIDE ELEVATION

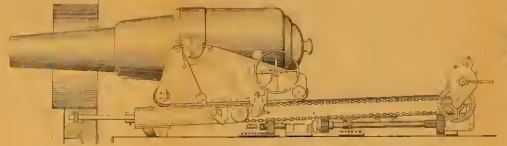


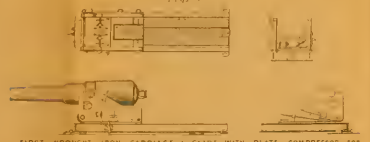
CUNNINGHAM'S ROPE GEAR



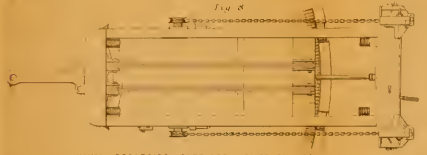
COMMON SLIDE CARRIAGE





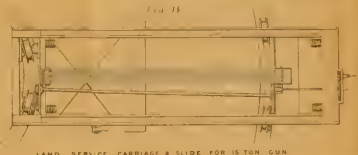


FIRST WROUGHT IRON CARRIAGE & SLIDE WITH PLATE COMPRESSOR FOR 70 PR GUNS

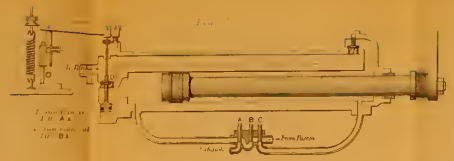


NAVAL BROADSIDE CARRIAGE & SLIDE FOR 12½ TON GUN

NAVAL REVOLVING CARRIAGE & SLIDE FOR 18 TON GUN

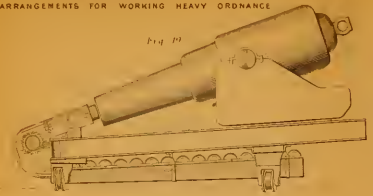


LAND SERVICE CARRIAGE & SLIDE FOR 18 TON GUN

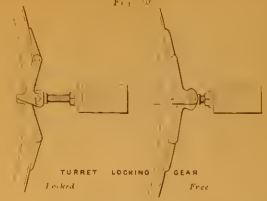


HYDRAULIC RECOIL PRESS

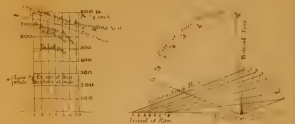
HYDRAULIC TUBE RAMMER



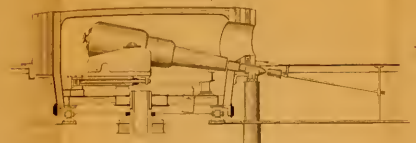
REVOLVING RAMMER



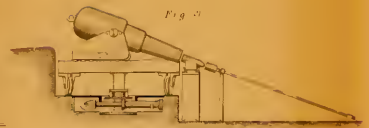
TURRET LOCKING GEAR



AIR-VESSEL PRESSURES & IN HYDRO-PNEUMATIC CARRIAGE



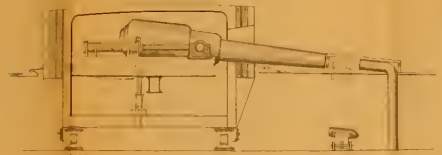
TURRET WITH TWO 38 TON GUNS, SHOWING LOADING FROM BELOW & HYDRAULIC BUFFER



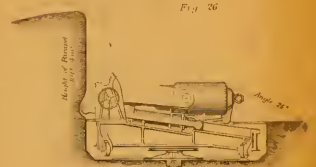
25 TON GUN, WORKED & LOADED BY HYDRAULIC MACHINERY IN LAND SERVICE BARBETTE

TUBE RAMMER IN IRONCLAD CASEMATE

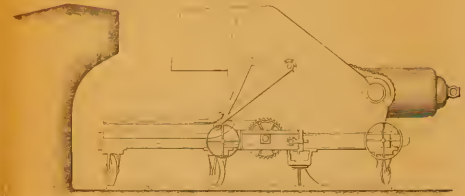
TURRET FOR TWO 16 INCH BREECH LOADING GUNS, WORKED BY HYDRAULIC MACHINERY



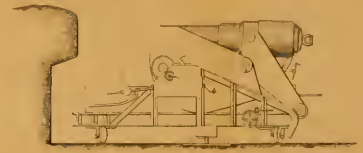
TURRET FOR TWO 16 INCH GUNS, WITH OUTSIDE LOADING



DISAPPEARING GUN ON HYDRAULIC SYSTEM



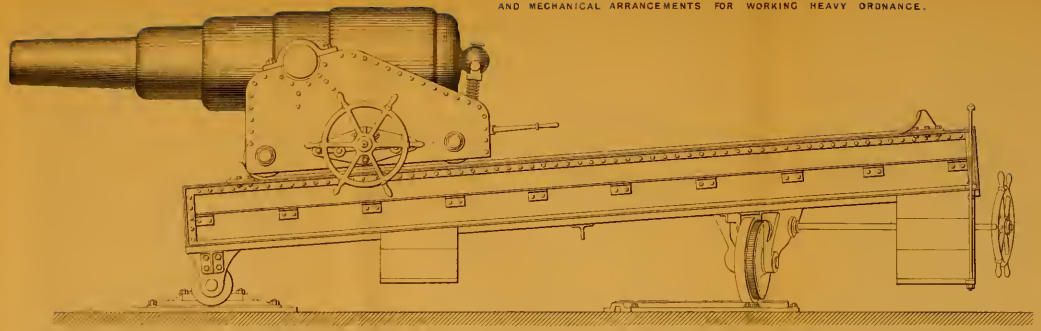
MONCRIEFF COUNTERWEIGHT CARRIAGE (ELSWICK PATTERN) FOR 12½ TON GUN



MONCRIEFF COUNTERWEIGHT CARRIAGE FOR 7 INCH GUN

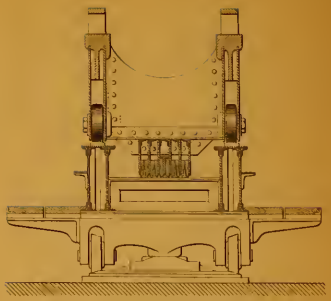
GUN CARRIAGES,

AND MECHANICAL ARRANGEMENTS FOR WORKING HEAVY ORDNANCE.

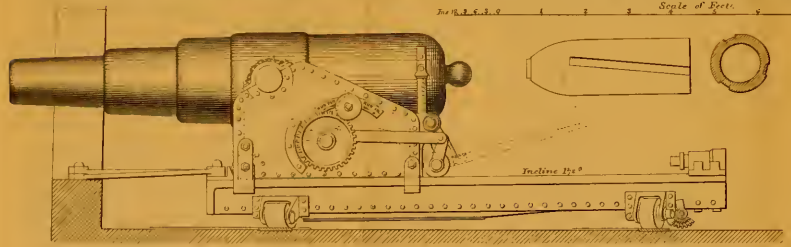


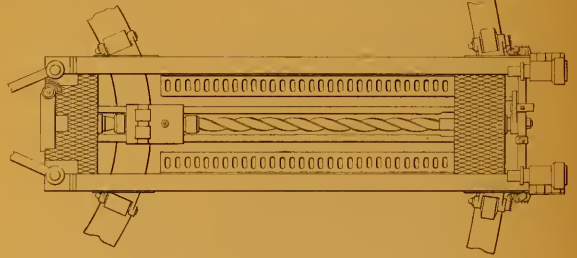
WROUGHT IRON CARRIAGE AND SLIDE FOR 11 INCH BUILT UP CAST STEEL BLAKELY GUNS. 1864.

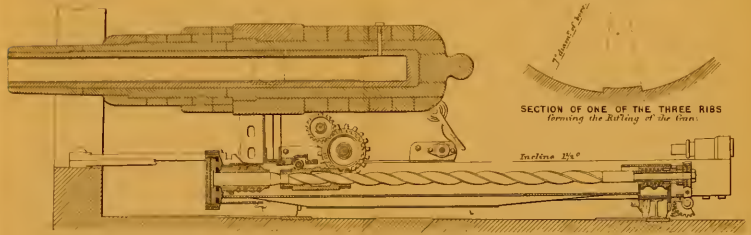
Scale of Feet.



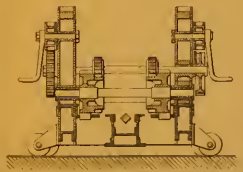
TRANSVERSE SECTION

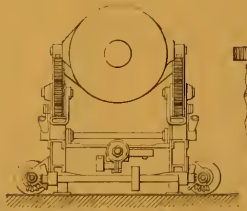


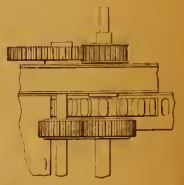




SECTION OF ONE OF THE THREE RIBS
forming the Rifling of the Guns.







WROUGHT IRON CARRIAGE AND SLIDE FOR 7 INCH GUN, FITTED WITH VAVASSEUR SCREW COMPRESSOR AND RUNNING OUT GEAR.

Scale of Feet.

J. VAVASSEUR, DELT.

THOS. KELL. LITH. 40 KING ST. COVENT GARDEN

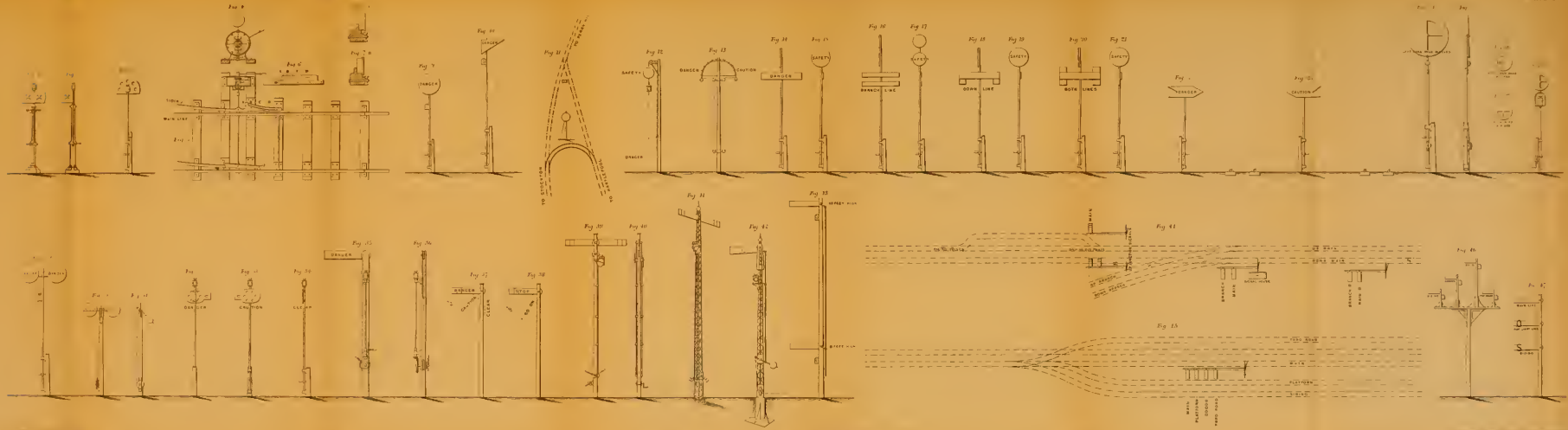
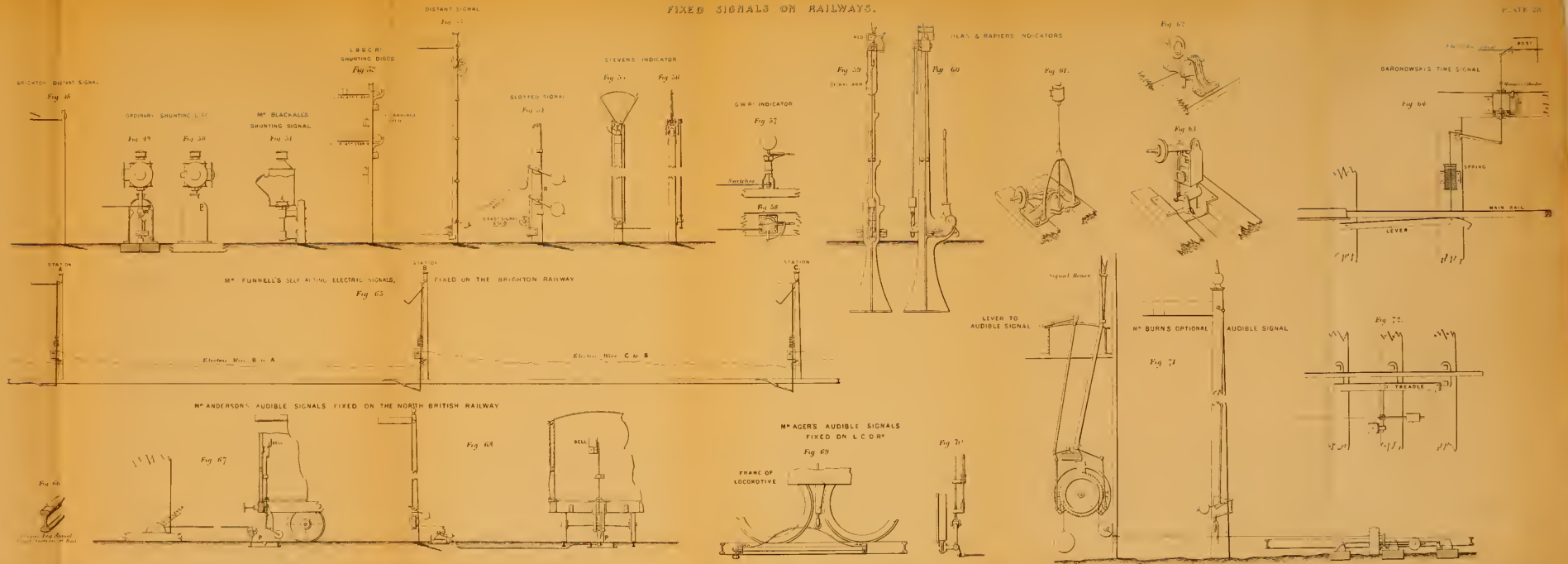


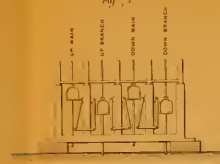
Fig 1
Fig 2
Fig 3
Fig 4
Fig 5
Fig 6
Fig 7
Fig 8
Fig 9
Fig 10
Fig 11
Fig 12
Fig 13
Fig 14
Fig 15
Fig 16
Fig 17
Fig 18
Fig 19
Fig 20
Fig 21
Fig 22
Fig 23
Fig 24
Fig 25
Fig 26
Fig 27
Fig 28
Fig 29
Fig 30
Fig 31
Fig 32
Fig 33
Fig 34
Fig 35
Fig 36
Fig 37
Fig 38
Fig 39
Fig 40
Fig 41
Fig 42
Fig 43
Fig 44
Fig 45
Fig 46
Fig 47
DANGER
CAUTION
SAFETY
BRANCH LINE
DOWN LINE
BOTH LINES
MAIN LINE
UP MAIN
DOWN MAIN
UP BRANCH
DOWN BRANCH
UP GOODS
DOWN GOODS
UP PLATFORM
DOWN PLATFORM
UP LOOP
DOWN LOOP
UP SIDING
DOWN SIDING
UP MAIN LINE
DOWN MAIN LINE
UP BRANCH LINE
DOWN BRANCH LINE
UP GOODS LINE
DOWN GOODS LINE
UP PLATFORM LINE
DOWN PLATFORM LINE
UP LOOP LINE
DOWN LOOP LINE
UP SIDING LINE
DOWN SIDING LINE


BRIGHTON DISTANT SIGNAL
Fig 48
ORDINARY SHUNTING SIGNAL
Fig 49
Fig 50
Mr BLACKALLS SHUNTING SIGNAL
Fig 51
L B & S C R SHUNTING DISC
Fig 52
DISTANT SIGNAL
Fig 53
SLOTTED SIGNAL
Fig 54
STEVENS INDICATOR
Fig 55
Fig 56
G W R INDICATOR
Fig 57
Switches
Fig 58
RED
Fig 59
Fig 60
HILL & RAPIERS INDICATORS
Fig 61
Fig 62
Fig 63
BARONOWSKIS TIME SIGNAL
Fig 64
POST
SPRING
MAIN RAIL
LEVER
Mr FUNNELL'S SELF ACTING ELECTRIC SIGNALS, FIXED ON THE BRIGHTON RAILWAY
Fig 65
STATION A
STATION B
STATION C
Electric Wire B to A
Electric Wire C to B
Mr ANDERSON'S AUDIBLE SIGNALS FIXED ON THE NORTH BRITISH RAILWAY
Fig 66
Fig 67
Fig 68
BELL
Mr AGER'S AUDIBLE SIGNALS FIXED ON L C D Y
Fig 69
FRAME OF LOCOMOTIVE
Fig 70
LEVER TO AUDIBLE SIGNAL
Signal Lever
Mr BURN'S OPTIONAL AUDIBLE SIGNAL
Fig 71
Fig 72
TREADLE

FIXED SIGNALS ON RAILWAYS.

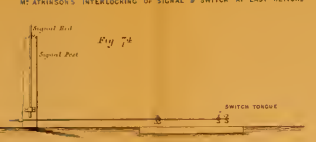
Mr GREGORY'S INTERLOCKING OF SIGNALS.

Fig 73



Mr ATKINSON'S INTERLOCKING OF SIGNAL & SWITCH AT EAST RETFORD

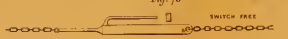
Fig 74



GOOSE NECK LOCK

Fig 75

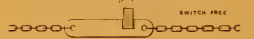
Fig 76



NOTCH LOCK

Fig 77

Fig 78



SWITCH GEAR

Fig 80.

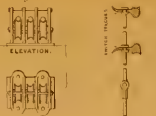


Fig 79

Fig 81

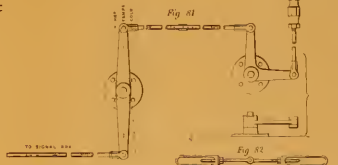


Fig 82

EXPANSION COUPLING

CHAMBERS' INTERLOCKING GEAR

Fig 83

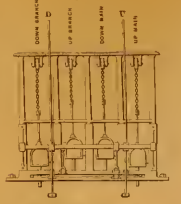


Fig 84

Fig 85

CHAMBERS'

Fig 86

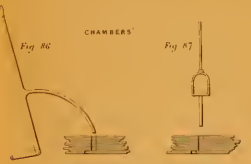


Fig 87

STEVENS & SONS INTERLOCKING

Fig 88.

Fig 89

PLAN VIEWS. LEVERS IN SECTION.

SAXBY & FARMER'S INTERLOCKING.

Fig 90.

Fig 91.

Fig 92

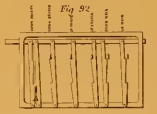


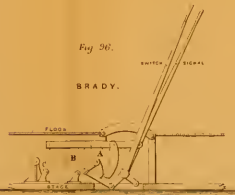
Fig 93

Fig 94

LANE

Fig 95.

Fig 96.



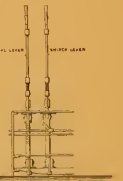
BRADY.

LIVESEY & EDWARDS' INTERLOCKING.

Fig 97.

Fig 98.

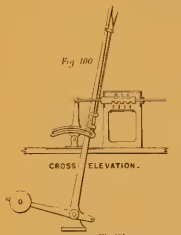
Fig 99



CROSS ELEVATION
EASTERBROOKS' RECENT GEAR.

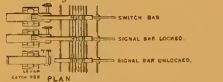
FRONT ELEVATION

Fig 100



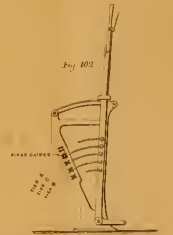
CROSS ELEVATION.

Fig 101



PLAN
SAXBYS' RECENT.

Fig 102



CROSS ELEVATION

Fig 103

PLAN
STEVENS' RECENT.

Fig 104

PLAN OF TOP PLATE

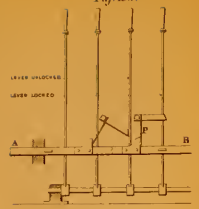
Fig 105

PLAN OF LOCKS.
POOLE

FIXED SIGNALS ON RAILWAYS.

RECENT INTERLOCKING APPARATUS.

Fig: 106.



Mr BUCK.

Fig: 107.

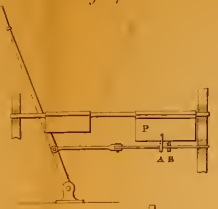


Fig: 108.

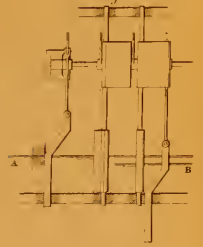


Fig: 109.

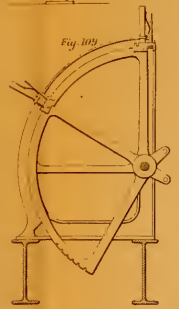


Fig: 110.

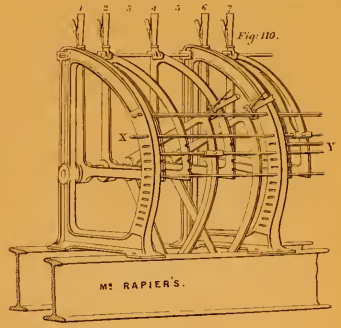


Fig: 111.

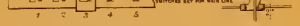
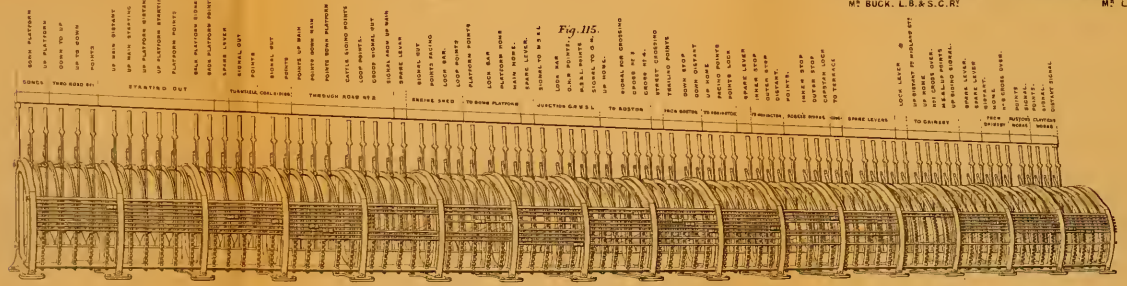


Fig: 112.

Fig: 113.

Fig: 114.

Fig: 115.



EXAMPLE OF LOCKING FRAME FOR LEVEL CROSSING. — 80 LEVERS.

Fig: 116.

MESSRS LIVESEY & EDWARDS'. IMPROVED BY MESSRS SAXBY & FARMER.

Fig: 117.

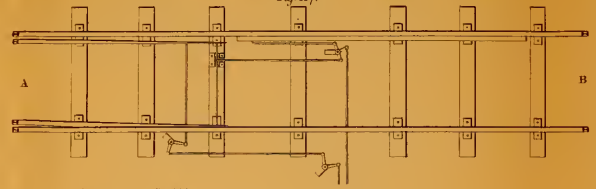


Fig: 118.

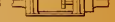
Fig: 119.

Fig: 120.

Fig: 121.

Fig: 122.

Fig: 123.

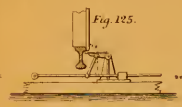


IMPROVED BY Mr RAPIER.

Fig: 124.

Mr BRADY. S.E.R.

Fig: 125.



Mr BUCK. L.B.&S.C.R.

Fig: 126

Mr LUKE. G.W.R.

Fig: 129.

Mr HARRISON. N.E. RAILWAY.

Fig: 130

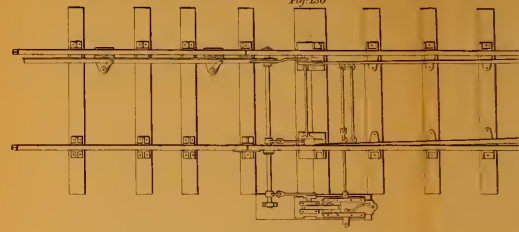


Fig: 127.

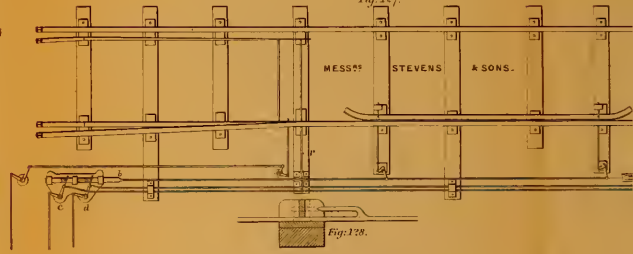
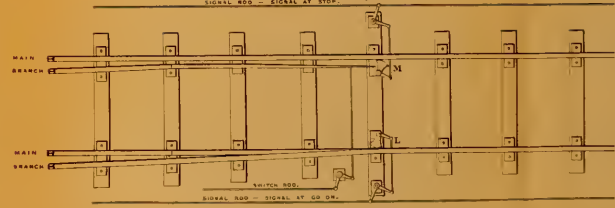


Fig: 128.

Fig: 132



MESSRS Mc KENZIE, CLUNES & HOLLAND.

FIXED SIGNALS ON RAILWAYS.

REGENT INTERLOCKING APPARATUS.

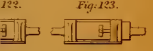


Fig: 129.

Fig: 130

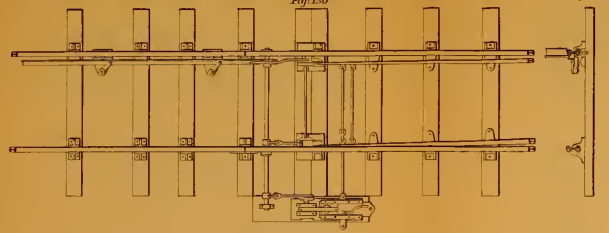


Fig: 131

Fig: 127.

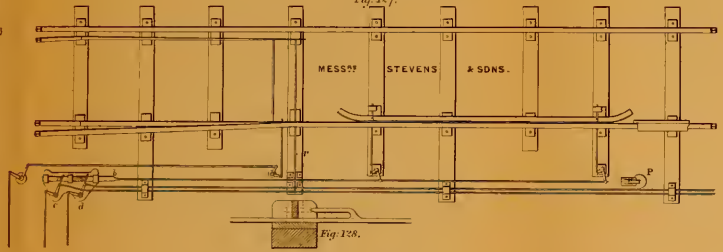
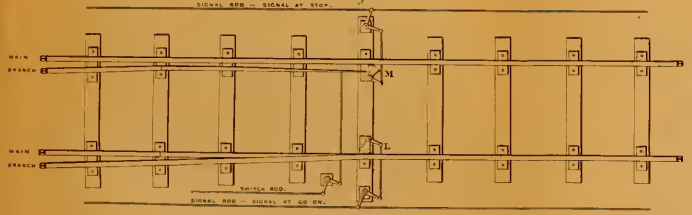


Fig: 128.

Fig: 132.



MESSRS MCKENZIE, GLUNES & HOLLAND.

Fig: 133

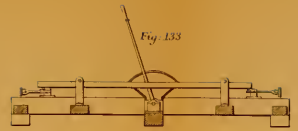


Fig: 134.

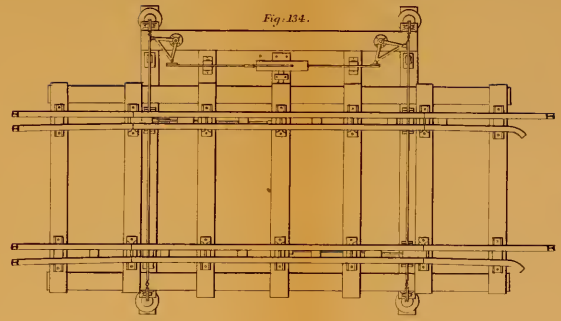


Fig: 135.

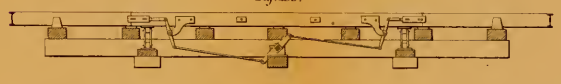
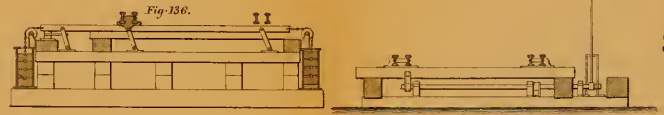


Fig: 136.



MR R. PRICE WILLIAMS' SWITCHES.

Fig: 137.

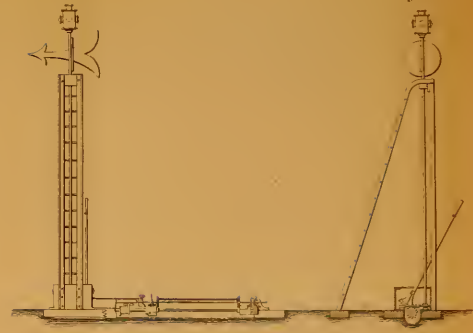


Fig: 138.

Fig: 139.

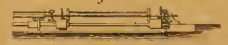
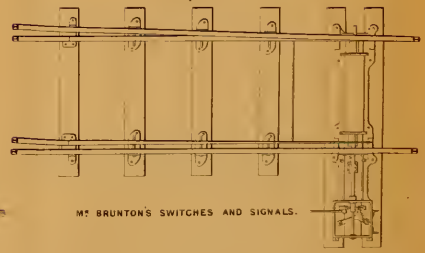


Fig: 140

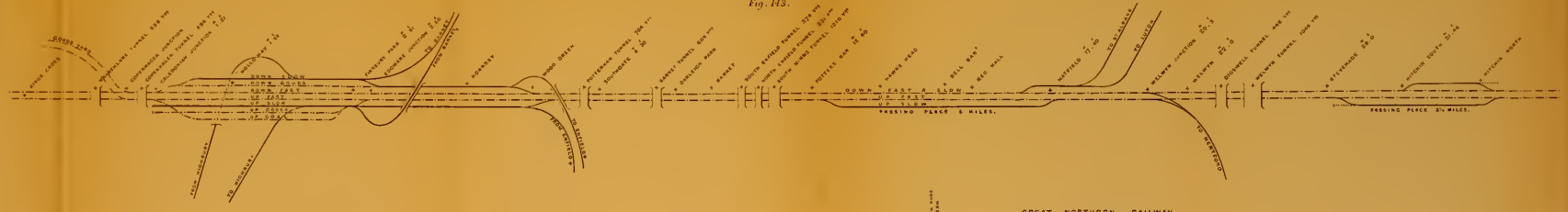
Fig: 141



MR BRUNTON'S SWITCHES AND SIGNALS.

GREAT NORTHERN RAILWAY.

Fig. 113.



LONDON, BRIGHTON & SOUTH COAST RAILWAY.

Fig 112.

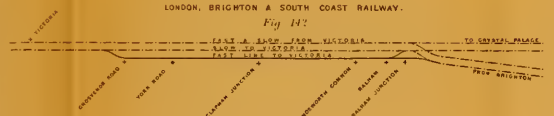
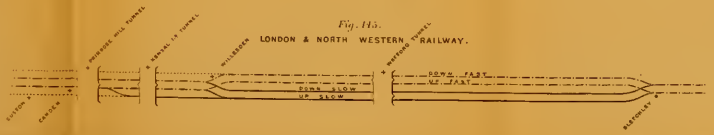


Fig 114

LONDON & NORTH WESTERN RAILWAY.

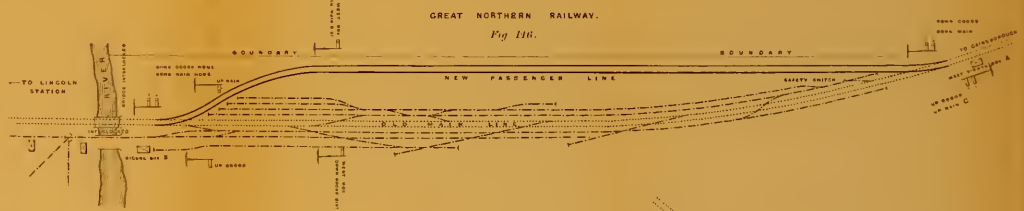
Fig. 115.

LONDON & NORTH WESTERN RAILWAY.



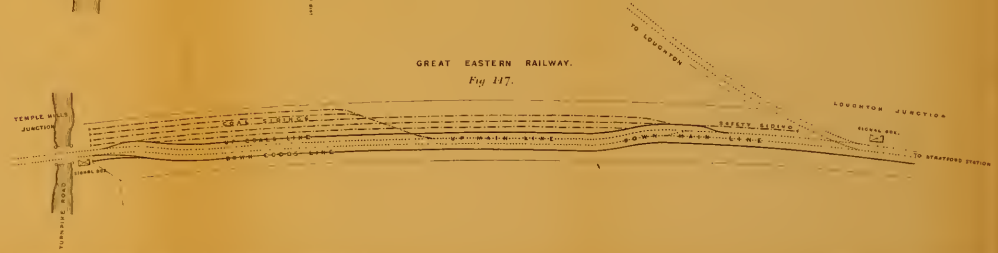
GREAT NORTHERN RAILWAY.

Fig 116.



GREAT EASTERN RAILWAY.

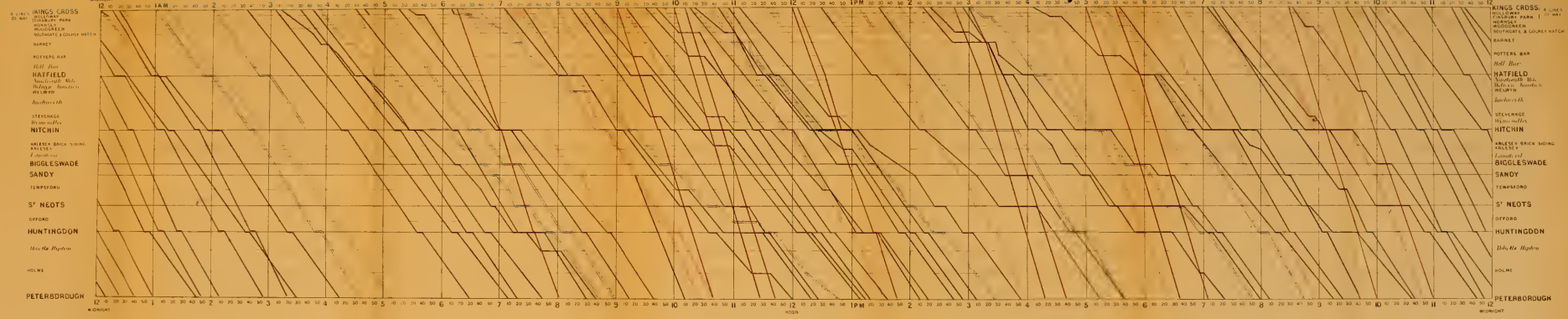
Fig 117.



RAILWAY WORKING.

DIAGRAM OF WORKING TIME TABLE OF GREAT NORTHERN RAILWAY FOR APRIL 1874

PLATE 32



Express Passenger Trains shown thus ——
Ordinary D. W.

Express Goods Trains shown thus ——
Ordinary D. W.

Coal Trains shown thus ——
Empties W.

7939
85

NORTHEASTERN UNIVERSITY LIBRARIES
3 9358 00852431 3

NORTHEASTERN UNIVERSITY LIBRARIES
3 9358 00852431 3